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GEOLOGISTS' ASSOCIATION

(FOUNDED 1858)

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Edited by
K. S. SANDFORD

*(Authors alone are responsible for the opinions and facts stated in
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Proceedings of the GEOLOGISTS' ASSOCIATION

WORK FOR AMATEUR GEOLOGISTS

By E. ERNEST S. BROWN, M.B.E., F.G.S.

(Presidential Address read 4th March, 1949)

IN the four years, 1945-8, 720 new members have been elected to our Association. I do not know the proportions in that total of professional, amateur and student geologists. It must, however, include a sufficiently large number of amateurs to permit me, an amateur myself, to offer some suggestions to them for geological work, which may add to their interest in our science and further the objects of the Association. This Address is, therefore, offered to new amateur members.

In January, 1859, our first President, Toulmin Smith, gave an inaugural address entitled "The Finding of True Facts." He gave as an object of the new Association that it should be the depository of many observations which, but for its existence, would remain buried in notebooks. Also he wisely stated that "Geology is a study which . . . can be learnt only in the field. The very power to judge rightly of its facts and to marshal them in available order must be got in the field."

"The Finding of True Facts," an inspired title, its tautology emphasising the critical severity needed in the search for truth. Since then, the traditional home of that shy maiden has not remained only at the bottom of the well. For oil geologists, she has migrated to the bottom of a mile-deep boring and, for field geologists, to the bottom of an auger-hole. She is still elusive, wherever located, and I want to put before you tonight some ways in which the search may continue.

I have known many new members who were attracted to geology because, sometimes quite late in life, they had become aware of the fascination of its major concepts, because new horizons of thought and imagination were disclosed by subjects such as Alpine tectonics, continental drift, the geological time scale and the proof of evolution by fossil evidence. In response to their enquiries they had been advised to read a selection of books, invest in one or more general textbooks; above all, to join the Geologists' Association and to attend its field meetings. These things they have done diligently and have been well rewarded for their time and trouble. After a while, however, I think the question sometimes arises, What next? However interesting it is to learn to understand the work of others and to follow the progress of research, to many of us there is always

the urge to be up and doing something for ourselves. In the vast range of our science there is ever the opportunity to find and properly record additional "True Facts" and such work provides a satisfaction, supplementary to and greater than, the study of the work of others. It is to such amateur members, limited in experience of the practical aspects of geology, to whom I venture to offer suggestions.

FIELD MEETINGS

Our field meetings have been called the "cream" of the Association's work. Attendance thereat hardly seems to be the practical work of my subject, although it would be incorrect to regard such attendance (*sans motor-coaches*) as passive in the physical sense. At field meetings members are not restricted merely to an interest in the Director's demonstrations. It is a truism that we benefit from most things only in strict proportion to what we put into them of ourselves. An excellent example is afforded by a geological excursion. The more the preparation in advance, the greater is the interest in the field. Directors usually publish in the circulars adequate geological references to the district to be visited or to the subject of the meeting. I advise strongly that members would do well to read up these references beforehand. They will then be able to ask worthwhile questions in the field and share in discussions that may arise.

Best of all are our longer field meetings. With a party spending 10 days or more together, the new member may make valuable contacts with more experienced members, who will willingly help him. Of their willingness to help, professional and amateur alike, there is no doubt. Moreover, each district visited will have been selected specially for its geological interests, which usually cover a wide range of subjects. There is also time for those discussions which we all enjoy, but for which opportunities seem to become ever rarer.

A counsel of perfection, when the opportunity can be found after a field meeting, is to go over the ground again alone. There is more time then for collecting, sections may be studied without interruption, and the leader's remarks and the party's discussions may be recalled and reviewed with the evidence at hand.

An active rather than a passive attitude to our field meetings provides, therefore, both an introduction to and excellent training for the work I am about to suggest.

COLLECTING

Some of us were first attracted to geology through fossil collecting in schoolboy days; others have started a collection as a result of the opportunities provided by the Association's field meetings.

There are few better ways for the amateur to widen his knowledge of geology than by making a general collection of fossils, rocks and minerals. He will have no difficulty in remembering the fossil which has taken an hour to extract in the quarry, followed perhaps by many hours at home spent in freeing it from its matrix by careful "needlework"; or the mineral specimen associated with a burn from the blowpipe or the rocks used for thin-sections of his own preparation. They will not only be cherished specimens, but the means whereby the collector has acquired, half unconsciously, a considerable knowledge of our science.

From the general collection the amateur may later concentrate on a specialised group. Almost any detailed study in geology demands the assembly of some kind of collection, which may consist of fossils, minerals, rocks, detritals, etc., according to the work undertaken. In particular, an intensive study of the rocks and fossils of the district in which the geologist lives is obvious work at hand.

Nowadays much attention is being given to micro-faunas, and their discovery and study provide a wide field as yet only partially explored. It is an excellent practice to collect a large quantity of any sediment being studied (a 7-lb. biscuit tin holds a suitable amount and is an ideal container if you are using a car) and by sieving, or elutriation, work through the residues for foraminifera, ostracods, etc. Of equal importance is the search among such residues for far-travelled erratics. A similar detailed examination should also be made of sediments generally said to be unfossiliferous because they do not yield a macro-fauna.

It is now realised that some sediments which cannot be zoned satisfactorily from their known fossil assemblages, or because they have hitherto been considered barren, may yet provide a valuable zonal sequence from their micro-fauna. Here is work indeed for the amateur geologist who is prepared to devote much time and specialised study in a direction which may give most useful results. Such problems may require him to evolve his own technique for collecting and preparing the material.

Collecting, therefore, both in general and in specialised form is to be strongly advocated, but there are associated with amateur collecting one serious disease and two matters for grave warning. The disease, often of slow growth but sometimes innate, is known as the "magpie habit." I have known serious cases. It is a passion for indiscriminate collecting over a long period of years, limited only by travelling facilities and the power of the purse. Once the specimens have been acquired, no use is made of them for scientific purposes; they are kept solely for the gratification of the owner-magpie. Amid cabinets, even rooms full of specimens of all kinds, there lie buried rare specimens or unique assemblages from particular sites, which would be of the greatest value to the

specialist, whose research is handicapped for lack of them. There is just one antidote to the disease. Specimens which are rare or sufficiently important to be of interest to the research worker should be presented to a national or university museum. They are then available to both specialists and students, and the collector will have the more worthy gratification that his record of museum registered numbers of the specimens which he has presented, represents a real contribution to our science. If he does not, he merits all the curses applied to and the fate of that similar bird, the "Jackdaw of Rheims."

The first of my warnings to the amateur collector relates to labelling. I assume that all collectors know that a specimen is of little or no value unless the precise horizon, and site from which it came, is certain. Many of us have been content to label our specimens by means of cards at the bottom of open trays kept in a cabinet. In a peaceful world this method should suffice. In 1940, however, I found it otherwise, as a result of a nearby bomb and, worse, the subsequent attentions of emergency removal men, working in my absence. It is a long and difficult task to find the proper home of every specimen in a drawer that has been thoroughly shaken up, and there must remain doubtful cases where two fossils of the same species came from different localities.

The only safeguard is the arduous one of a reference number in paint or indelible ink, or for small specimens a disc of gummed paper, being given to every specimen, with the number repeated on the relative label, catalogue, etc. Those starting a collection will be well advised to take this extra precaution, necessary, we trust in future, only against the menace of the removal men or the accidental upsetting of a drawer.

My second warning concerns all of us in due course and relates to the final disposal of a private collection. When I was your General Secretary I had most difficult enquiries from executors and relatives. They were in two categories. Either the relatives were anxious to get rid of the remains of the "old man's hobby" in the easiest and quickest way or the collection was given an altogether inflated scientific and sometimes monetary value. To advise that a museum official should be invited to examine the collection did not always solve the problem.

In early years one is inclined to collect, not only for the good and sufficient reasons already stated, but because one looks forward to doing "one day" some work on this or that group of rocks or fossils. Later one realises, as in other things, that "one day" never comes and by that time plans for work in retirement should already be mature. Of course, the collector will need to retain much longer the material on which he is still working and probably add thereto as long as he is physically active, but I suggest that it is very desirable to disperse most of a collection in the first years of

retirement. To such members I would say : You have had the fun of collecting ; enjoy also the pleasure of disposing of the material where it will be most appreciated and where the valuable part may find a permanent home. Assuming that rare and important specimens have already been presented to a national collection, I can conceive of no greater satisfaction than the knowledge that other specimens you have used and valued yourself will become available for the furtherance of our science by a later generation. Many museums and teaching collections suffered grievous losses by bombing, others have gaps in their collections which perhaps in part you may fill. Any centre of geological teaching will welcome a set of specimens from a type locality or a set specially assembled in connection with a published paper. The one requisite is that there shall be no doubt whatever as to the formation and precise locality from which the specimens were obtained. Where there is a local museum with a genuine geological section, that is obviously the appropriate home for locally collected specimens.

There will always be a residue from work in hand and provision should be made for this and for the collection of the geologist who may die in harness. Executors will be grateful for written instructions, the fruits of many years of work will be safeguarded, and suburban rock gardens will be the poorer.

I have heard bitter complaints from amateur collectors about the alleged practice of palaeontologists of changing needlessly the generic and specific names of well-known fossils. The point, of course, is the charge of needless change. If there are such cases, we may safely leave fellow palaeontologists to deal with the crime. In nearly all cases, changes are for good and sufficient reasons in accordance with the International Rules of Zoological Nomenclature, and the complaints are ill-founded because these reasons are not understood. There is a small book, *Procedure in Taxonomy*, by Schenk & McMasters, 1936, which not only explains why changes are necessary, but provides a glossary of terms and a reprint of the Rules with comments. A study of this useful work must disarm criticism. Anyway, for ordinary purposes, if we use the older names, our specialist friends will know what we mean and they will assist us in the use of correct nomenclature for our publications.

TEMPORARY SECTIONS

In my time there have been two attempts to provide a co-ordinated method of recording temporary sections. Both failed, almost from the initial stages. Record cards were printed, a list of observers was compiled, and a registrar eagerly awaited results, which did not materialise. We are all too busy ; unbeknown, a section may be opened and closed within two minutes' walk from

our daily route to the station and no advice system, by local roundsmen, postmen or the like, has proved effective. Works contractors and municipal engineers may be sympathetic, but cannot be relied upon to advise the local geologist. Yet with new arterial roads, housing estates and the plans for dispersal outwards from the large cities, temporary sections are and will be frequent.

Here then is ideal work for the amateur geologist and particularly when he has retired from business or professional life. The measure of his success will depend upon his enthusiasm and alertness. With the "cut and fill" methods for excavations and the "cut and slope off" procedure in road making, many temporary sections remain available for a very little while. Nowadays "next week" is often too late, when a filled-in section mocks the observer with just sufficient evidence to show what he has lost. Speed may be the essence of his undertaking.

A temporary section once discovered, it is therefore a positive duty to make a proper record forthwith. The essential features of the record should be the registration of the exact site on a six-inch map, careful measurement of the section, identification of the strata exposed and the collection of samples of the deposits and of erratics or fossils, when present. If the section presents any unusual features, differs in any important respect from the published geological records of the neighbourhood or from the one-inch map of the Geological Survey, more work is required. It may be desirable to invite others to look at the section with you, to take auger samples from the bottom of the section or fill the 7lb. biscuit tin already mentioned, to obtain an adequate sample of the material for treatment at home. In all cases good photographic records are most desirable.

Our *Proceedings* contain numerous records of temporary sections provided by amateur members and brief factual papers of this character are always welcome when there is something new to record. Further, in special cases, when a section fortunately remains open and unspoilt for a considerable time, it may be possible to arrange for a field meeting to the district, with the section as the principal object of the visit. It is now our practice to publish the description of such a section as a brief paper and the report of the meeting as an appendix thereto. This course ensures appropriate indexing of the record and avoids its "burial" in the meeting report.

The Geological Survey welcomes carefully recorded details of temporary or permanent sections, provided the precise sites are noted so that they may be located with confidence and used for reference.

LARGE-SCALE MAPPING

I come now to a proposal for some definite geological work, which is not dependent on the chance discovery of temporary

sections or favourable sites for collecting. It is to undertake the geological mapping of a selected area on the scale of six inches to the mile. The benefits, both direct and indirect, to be derived from such work may be numerous to the geologist and not inconsiderable to progress in research.

First of all, however, let me deal with possible criticism. It has been held that geological mapping is the province of the professional geologist and that it should be carried out only by fully trained or academically approved personnel. The short answer is to call attention to the wealth of original work, including, or based on, six-inch mapping by amateur geologists, which has been published in our *Proceedings* during the last 25 years. The outstanding feature differentiating professional from amateur work of this kind is that the former has, of necessity, to be subject to some time limitation, whereas the time that the amateur may spend on any one area or particular task is virtually unlimited. Of course, the professional works faster and more efficiently. He has to. The time taken by the amateur is controlled only by his interest in and devotion to the work in hand.

Let us assume an amateur member is prepared to give my proposal a trial, but that, being inexperienced in field work, he is diffident of obtaining trustworthy results and feels, therefore, that much labour and some expense may be abortive. Providing he has already a real love of the countryside—his interest in geology as a member is assumed—I am convinced that the suggested work will be its own reward. To examine a selected area in utmost detail, to traverse every footpath and literally to explore every field, copse and stream therein, in the search for geological evidence, gives an intimate knowledge of a piece of country which is not likely to be gained in any other way—at least by the townsman. Always there is the exciting element of discovery. At any time a small ditch section, a farm pit, even a rabbit scrape or a fortunate auger-hole, may yield just the evidence to confirm a cherished belief or to refute a theory. The result? A change in a line on the map, the establishment or removal of a fault, a change in dip, the pitch of an anticline or a dozen other possibilities bringing the map one stage nearer the truth. As the work progresses, all evidence available is called upon; every small topographical feature requires an explanation, ecology plays no small part and even the siting of human habitation and industry has a sound geological basis. “It is fun finding out”: that is one of the rewards to be culled by all and, in the process, there is added unto you training in observation, skill in interpreting your observations and the satisfaction of adding a few grains to the sum of geological knowledge.

The choice of an area for your mapping is one of the greatest importance and the selection should be based on two considerations (1) accessibility, (2) geological interest. Twenty years ago I should

have considered that the second was paramount, but with more experience and under present-day conditions of excessive fares and restrictions on motoring, reasonable access to a district is a vital matter. Whilst a tiresome journey may be endured in the first enthusiasm, after many visits and in bad weather it may well become the deciding factor for deferring a day in the field. Moreover, as the work progresses, you are likely to be led farther away from the direct route and find it necessary to visit adjacent areas more remote from home. Choose wisely, therefore, with due regard to time and ease of travelling.

For your first map and for geological interest, I would advise an area having outcrops of contrasting rock types, such as sandstone, clay and limestone with gentle dips or simple folding. These features may be determined from a study of the published one-inch maps of the Geological Survey. For the inexperienced, such country will avoid some major difficulties and above all ensure confidence and surety in the work undertaken.

Commence by purchasing in duplicate the six-inch Ordnance Survey sheets of the area selected. Keep one set for careful and continuous recording of your field work and cut the other set into field strips (four to the quarter sheet are recommended), which may be mounted on cardboard folders or kept in a field map-case.

Next make two or three traverses across the strike in order to familiarise yourself with the rock types, the varied scenery and vegetation of each outcrop, and with the general topography. At this stage it is well to visit at some length one or more quarries or adequate exposures in each formation to study the lithology and especially its variations.

You will then be ready to try to determine the first geological boundary lines on the map. Choose one where there is a sharp contrast such as sandstone against clay or a limestone between two softer deposits. Obviously the next line will be the top or base of the distinctive rock first selected and then you have fixed the width of one outcrop on the map. These lines will form a sound basis for mapping other formations above and below.

Do not look for problems ; plenty will arise as the work proceeds and they will call for much consideration. Every variation in width of outcrop must be explained by surface relief, change of dip, alteration in thickness of bed, or minor fold. Simple faults encountered have to be traced to fix their position and the number of beds affected. More complicated fault systems will need much speculation before you reach a solution and may need to be mapped on a still larger scale. Remember that the simplest solution, which satisfies all the evidence, generally proves to be the right one.

As the work goes on you will acquire the mapper's primary requisite—to think in three dimensions ; you will be led away on

many an interesting side-line, perhaps of geomorphology, of detailed lithology, stratigraphy or palaeontology. These afford relief and change from the steady recording of your boundary lines, the delineation of which should remain the sheet-anchor of your work.

Long before the mapping of the first area selected has been completed, you will be aware of new interests pressing for attention on adjacent sheets, but before yielding to the temptation it is well to place the work accomplished in permanent form. Some part of the work, or a portion of the actual mapping, may be of sufficient interest for a paper in our *Proceedings*. If your work has been in the Weald, the Weald Research Committee would be glad to receive a copy of your completed map.

The Geological Survey would appreciate copies of completed sheets, or portions thereof, provided the notes on the map record facts observed and the exact sites. It should be realised that the nature of the beds, measurements of thickness, dip, etc., are facts which all may use, whereas the map and your comments thereon are an interpretation of that evidence. The facts are, therefore, particularly valuable to the Survey, to which your interpretation is a useful supplement. I am authorised to add that, whilst the Survey cannot as a rule acknowledge work merely incorporated in their published maps, any information supplied will be acknowledged either in the accompanying Memoir in which it is used or in the Annual Report.

CONCLUSION

I have put before you some suggestions for practical work by amateur geologists. For inspiration, I refer you to the work, writings and biographies of past and present enthusiasts, of both professional and amateur status. I append a brief list of references which make clear that outstanding achievement has been linked with life-long enthusiasm for field-work.

Allusion has already been made to assistance from professional geologists and I assure new amateur members—those of longer standing know already—that they will find such help generously extended to them. Do not, of course, worry the specialists unnecessarily when a fellow amateur can give the information desired. Here I wish to pay a warm tribute to all the professional geologists and particularly to the Officers of the British Museum (Natural History) and of the Geological Survey, who have given me much kindly assistance in the past 35 years.

In 1958 the Association will celebrate its centenary, which will be the appropriate time for a review of its history and contributions to geological science. Due attention will no doubt be given to the good work done by amateur geologists throughout that period. My purpose tonight has been to suggest some ways by which that notable record may be continued, so that the final decade of our

first century may witness another advance in the finding and recording of "True Facts" for the increase of geological knowledge.

I acknowledge with gratitude some valuable suggestions from Dr. G. W. Himus and Mr. T. Eastwood on certain matters dealt with in this Address.

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PERMO-TRIASSIC GEOLOGY OF SOUTH CUMBERLAND AND FURNESS¹

By K. C. DUNHAM, D.Sc., S.D., F.G.S., and W. C. C. ROSE, M.Sc., F.G.S.

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SUMMARY

The Permo-Triassic rocks flanking the Duddon Estuary dip south-westward in three fault blocks defined by major N.N.W. faults downthrowing west. The Zechstein deposits include Brockrams (breccias) accumulated near the old Lake District landmass, passing south-westward into St. Bees Shale and Magnesian Limestone. Still farther from the old shore-line, the limestone gives place to massive anhydrite. Among the Zechstein sediments are grey, plant-bearing dolomitic siltstones, possible equivalent to the Hilton Plant Beds and Marl Slate farther east. The Bunter is represented by sandstone (St. Bees) 2,500 feet thick. Evidence is presented to show that in Furness the Bunter overstepped the Zechstein to rest directly on the Carboniferous limestones, and it is suggested that the haematite "sops" of that region originated in swallow holes formed beneath the sandstone. After mineralisation by solutions whose origin is still in doubt, further solution without mineralisation caused collapse and brecciation of the ore-bodies. The Keuper includes grey (Kirklington) sandstone, overlain by marl with halite deposits. The simplest interpretation of the subsurface geology beneath Walney Island suggests that the halite deposits are lenticular in form, and at different stratigraphical levels.

Petrographical descriptions of the sediments and evaporites are included.

INTRODUCTION

Geography.—The area of south Cumberland and Low Furness (Lancashire) underlain by rocks of Permian and Triassic age lies along the Irish Sea coast, flanking the estuary of the river Duddon, within one-inch New Series maps 47, 48 and 58 (Fig. 1). The rocks may be regarded as part of the discontinuous fringe of "New Red" round the Lake District. In south Cumberland they are present beneath the low coastal plain, about a mile wide, which lies between the foot-hills of Black Combe and the sea, though they are everywhere concealed by thick glacial deposits overlain near the coast by marine

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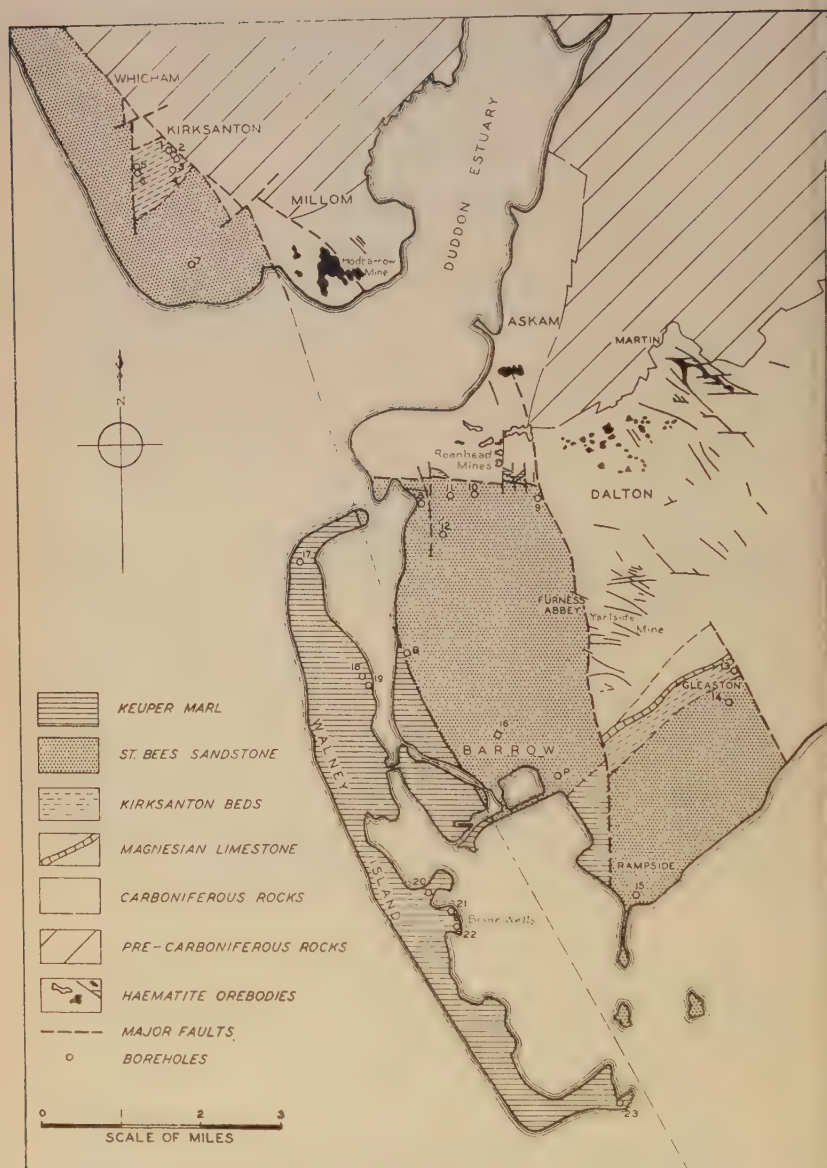


FIG. 1.—GEOLOGICAL MAP OF SOUTH CUMBERLAND AND LOW FURNESS.
Based on the resurvey of 1937–8.

warp and blown sand. East of the estuary, in Furness, the outcrop extends southwards from Sowerby Wood and Goldmire to Barrow-in-Furness, forming the low hills on which Barrow Golf Course is situated. At the southern end of this ridge a large quarry in red sandstone at Hawcoat was the source of most of the stone used in building the town. Red sandstone also forms the sides of the Vale of Nightshade, and yielded the stone from which the 12th-century Furness Abbey was built. Farther south, "New Red" rocks occur beneath the drumlins, glacial sand-deltas and marine warp which make the characteristic scenery of Low Furness, and extend as far as the southern tip of the peninsula. Barrow and Walney islands both have a "solid" foundation of Trias, but the surface is made up of low boulder-clay hills, linked on Walney by 25-feet raised beach and terraces of marine warp at various levels.

Only the St. Bees Sandstone and Magnesian Limestone crop out in Furness; our detailed knowledge of the Permo-Triassic here is based upon numerous borings in search of iron ore, coal, water and salt.

Previous Research.—The pioneer account of the New Red Sandstone in north-west England was that of Sedgwick (1836),* who mentions the Holebeck limestone exposures, and the red sandstone outcrops farther west. Binney (1847) also described the outcrop of the Magnesian Limestone and quotes the following analysis: SiO_2 11.65 per cent; MgO 8.95; CaO 29.80; iron oxides 9.45; CO_2 38.40; H_2O 1.75. Murchison and Harkness (1864) advocated a Permian age for the limestone and red sandstone, and considered the cemented breccias of limestone boulders commonly found resting on the Carboniferous Limestone and haematite deposits of Furness—known to the miners as Crab Rock—to be the equivalents of the Lower Brockram of the Vale of Eden. W. T. Aveline, who with A. C. G. Cameron carried out the primary six-inch geological survey of Furness, did not uphold this view, as he makes no mention of Brockram in the short memoir on Old Series one-inch sheet 91 N.W. (1873). About this time J. D. Kendall (1875) suggested that the Crab Rock is in fact cemented boulder drift of glacial origin and not Brockram, a view which we have confirmed. During the later years of the 19th century deep borings at Gleaston and Rampside considerably amplified the existing knowledge of the succession in Furness (Brogden, 1874; De Rance, 1899; Gaythorpe, 1903), and in 1887-8 Keuper Marl with salt was proved beneath Walney Island, though apart from a single unsited borehole journal (Sherlock, 1921, p. 80) no details of this occurrence have previously been published. The deepest boring in the Permo-Triassic rocks of the area was made in

* For list of References, see p. 36.

1902-3 at Davy Street, Barrow, an abstract being published in the *Proceedings* of the Barrow Naturalists' Field Club (1909).

In south Cumberland our main knowledge of the "New Red" rocks comes from borings around the hamlet of Kirksanton, accounts of which were given by Bernard Smith (1919, 1924), and near Haverigg. In the second publication cited, Dr. Smith presented evidence for the lateral passage of Brockram into St. Bees Shales in west and south Cumberland, and of marked irregularities in the sub-Permian floor.

Present Investigation.—In 1937 a resurvey on 6- and 25-inch scales of the iron ore-field of south Cumberland and Furness by the Geological Survey was begun, Rose being responsible for the area west of the Duddon, including Hodbarrow, and for the Lindal-Ulverston part of Furness, and Dunham for the remainder of Low Furness. A brief account of the general results has been published (1941) and a detailed memoir on the iron ore-field is contemplated. The Permo-Triassic rocks are only of limited interest in this connection, and the present account is designed to give a connected account of the "New Red" geology, including details that would be inappropriate in the memoir.

Since the completion of the survey the Hodbarrow Mining Company has drilled a deep borehole at Haverigg Haws. The cores were examined in the field by Rose and selected material has been investigated petrographically by Dunham. We express our indebtedness to the directors of that company for their co-operation during the resurvey and also to the Barrow Haematite Steel Co., the Millom and Askam Haematite Iron Co., Messrs. Kennedy Brothers and the Buccleuch Estates for placing unreservedly at our disposal their records of borings in the area. Our thanks are due to the Barrow Naturalists' Field Club for giving us access to their archives. The resurvey was carried out under the supervision of Mr. T. Eastwood, Assistant Director, to whom we also record our gratitude.

STRUCTURE

Major faults trending north-north-west split up the "New Red" outcrop into three main areas. The western area is limited to the east by the great Cumberland Boundary Fault which runs at the foot of Black Combe and is believed to continue south of the Duddon through Barrow Island and the Walney Channel. In Cumberland this fault brings Lower Palaeozoic rocks into contact with Carboniferous and "New Red"; in Furness it separates Bunter Sandstone from Keuper Marl. The Boundary Fault has been intersected by many boreholes near Kirksanton and by one near Haverigg, where St. Bees Sandstone is brought against Carboniferous Limestone of C_2 - S_1 age. The middle and eastern

blocks are wholly in Furness. The eastern boundary of the former is the complex Park-Yarlside fault system, while on the east side of the eastern block main faults extend south-south-east through Gleaston to reach the coast near Newbiggin. All three main faults thus downthrow west. Their ages, being post-Triassic, are taken to be Tertiary, but direct proof of this is lacking. A dyke apparently injected into one of the fractures associated with the Gleaston Fault is an olivine-dolerite (E.727, 17693-4)¹ composed of hypautomorphic labradorite crystals averaging 1-1.5 mm. long, bowlingite pseudomorphs after olivine, chlorite and red iron oxide which have extensively replaced other ferromagnesian minerals. Quartz and chlorite fill vesicles in the rock.

The dip of the measures is south-east in south Cumberland, south in the middle block in Furness, and south-east in the eastern block. It is appreciably less in amount and often different in direction from that in the underlying Carboniferous rocks, which had already been tilted, for instance round the High Haume anticline, by Armorican movements.

The northern margin of the outcrop in the middle block is believed to be traversed by a small east-west fault known as the Sandscale Fault, downthrowing south, but owing to marked variations in the lithology of the Zechstein deposits here it is difficult to assess the magnitude of this disturbance or to be quite certain of its continuity. A trial level driven southwards from Goldmire Quarry started in Carboniferous Limestone (S_2) and passed through the fault into St. Bees Sandstone.

In the vicinity of Yarlside Mine, the Park-Yarlside Fault brings the Bunter Sandstone of the middle block into contact with Carboniferous rocks. Lying between the sandstone and the massive limestones of S_2 and D_1 age is a narrow belt of shale. Smith (1924b) interpreted the relations here at least in part as a limestone scarp against which the sandstone was banked up, and adduced in favour of this view the much eroded character of the limestone face. The resurvey clearly indicates the continuity of the supposed scarp both to the north and south as a major fault. Farther south, it brings the base of the Permo-Trias on the east against beds at least as high as the middle of the Bunter. We return therefore to Aveline's view (1873, Fig. 1) that the relations at Yarlside are best explained by faulting. The "eroded" character of the limestone we believe to be due to solution in connection with the haematite mineralisation; the shale to be dragged in from the Gleaston Group (Carboniferous, D_2).

¹ Numbers prefixed by "E" in brackets refer to the English sliced rock collection of the Geological Survey and Museum.

CLASSIFICATION

The general succession of beds is as follows :—

<i>Approximate Continental Equivalent Keuper</i>	<i>Lithology</i>	<i>Thickness Feet</i>
	Red, blue and green gypsiferous marl with thick lenses of halite	1,260+
	Grey and red sandstone (? Kirklington Sand- stone)	
Bunter	Red sandstone with thin grey or white layers and a few marl partings (St. Bees Sandstone)	2,500+
	Red gypsiferous shale and marl (St. Bees Shale) with Brockram in south Cumberland	up to 670
	Magnesian Limestone	0-65
	(passing south into massive anhydrite)	(0-105)
Zechstein	Grey shale with plants (Hilton Plant Beds)	up to 65
	Brockram	0-90

This succession is closely similar to that of north-west and west Cumberland, described in the memoirs of the Geological Survey on Carlisle, Longtown and Silloth (1926), Whitehaven (1931) and Gosforth (1937), and the present area represents a southward prolongation of that province, showing, in Hilton Plant Bed times at least, a connection with the Vale of Eden also (Smith 1924a, Hollingworth 1942). While palaeontological evidence is lacking except in the grey shales and Magnesian Limestone, the general correlation indicated above is in accordance with present ideas. The classification of the red sandstone formation by Murchison and Harkness (1864) as Permian has not been upheld by Geological Survey practice, the St. Bees and Kirklington sandstones being shown on all modern geological maps as Trias (f), while the St. Bees Shale is regarded as transitional between Permian and Trias (e-f). The history and status of the subject are fully discussed in the Carlisle Memoir (1926, p. 8).

As in west Cumberland, there is ample evidence in the present area that the breccias accumulated near the old Lake District land mass, and that their diachronous equivalents off-shore include St. Bees Shale and Magnesian Limestone. The Limestone, moreover, as Hollingworth (1942) has pointed out, itself passes laterally into massive anhydrite to the south-west, justifying his views as to the relative distribution of chemical deposits in the Zechstein basin. Salt deposits of Zechstein age are not, however, known in this region.

The whole of the "New Red" deposits described here would fall within the Epeiric System proposed by R. L. Sherlock (1928 and 1948).

THE PRE-PERMIAN SURFACE

The folded Ordovician and Silurian rocks of the Lake District were partly, but perhaps not wholly covered with Carboniferous

rocks. From earliest Carboniferous at least to Millstone Grit times, quite distinct facies were deposited north and south of the east-west Eskdale Axis. Following the Armorican movements, great thicknesses of sediments were eroded off, so that when the Permian breccias began to be accumulated Lower Palaeozoic rocks were once more exposed close to our area, and the surface had been eroded across Carboniferous rocks tilted to the south-west (south Cumberland), south or south-east (Furness). There is every reason to believe that the Lower Palaeozoic rocks at this time formed high ground, probably with an abrupt change of slope, perhaps leading to a rock-pediment, lying somewhat south of the present margins of the fells. The breccias, as in a modern "basin and range" region, would be accumulated mainly in the vicinity of the mountain front, while in the basin muds accumulated to form shales, or evanescent playas dried up, depositing gypsum.

Irregularities in the pre-Permian surface near the mountains were filled up with breccia. Smith (1924a) has suggested that for a time there was a low escarpment of Carboniferous Limestone near Kirksanton, but here we are of the opinion that the evidence, derived mainly from one borehole, might also be explained by reference to a swallowhole, comparable with the "sops" of Furness, to be described later. The complex relation along the northern margin of the Furness outcrop, where breccias rest for the most part on the Gleaston Group of shales, limestones and sandstone (Carboniferous, D_2) can most readily be explained by unevennesses of the surface. Sandscale No. 17 borehole, for example, showed glacial drift to -77 feet O.D., red sandstone to -167, Brockram to -183, resting on Carboniferous (D_2). A study of adjacent borings in the Carboniferous suggests that the breccia and sandstone occupy a hollow in the pre-Permian surface, and the same may be true in the vicinity of Sowerby No. 10 borehole, $1\frac{1}{4}$ miles south-east of The Moors.

ZECHSTEIN

South Cumberland.—Numerous boreholes near Kirksanton have proved a series of variable beds consisting of red and grey shale, breccias, magnesian limestone, and marls underlying Glacial deposits and resting unconformably upon Carboniferous Limestone of S_2 - D_1 age. The general dip is to the south-east at about 10° , and the same series of beds, though showing important lithological differences, have also been recorded beneath St. Bees Sandstone at a depth of from -920 to -1,750 feet below O.D. in a borehole on Haverigg Haws (see below). In this case the beds rest on D_2 Carboniferous Limestone. For stratigraphical purposes the evidence is insufficient to show how the different members of the series crop out beneath the drift deposits, and for this reason they have been grouped together in this area as the Kirksanton Beds.

The outcrop of these beds, beneath drift, and faulted on the north, east and west sides, extends for about a mile south of Kirksanton, where it is followed to the south by that of the overlying St. Bees Sandstone. The general succession in this ground appears to be :—

4. St. Bees Sandstone
3. Red Shale and Brockram
2. "Grey Beds" with magnesian limestone and marls
1. Brockram and shale

The sections illustrated in Fig. 2 will show, however, that there is considerable variation, both in lithology and thickness. Bernard Smith, in the paper referred to, gave an explanation of this, and compared the beds with those of similar age farther north in west Cumberland and in the Vale of Eden. In particular, he drew attention to the lateral passage from east to west of Brockram into shale, a conclusion which is supported generally by a comparison between the Kirksanton boreholes and that of Haverigg Haws (see below) sunk after Smith's paper.

It is by no means easy to describe the details of the succession near Kirksanton. No doubt this is partly due to the difficulty of interpreting the borehole journals, since only one or two of the cores of the more recent holes were geologically examined (by Bernard Smith). Clearly, however, there is evidence of rapid lateral change. In most of the holes the lowest beds are about 60-70 feet thick and consist of shales with breccias and occasional magnesian limestones. In one borehole, however (not reproduced), the lowest beds appear to be over 200 feet thick, and this record was used by Smith as evidence of the existence of a buried scarp of Carboniferous Limestone. An alternative explanation which is now favoured is that this borehole entered a limestone hollow, in structure like one of the Furness "Sops," within which Permo-Triassic material has accumulated.

The Grey Beds are variously described in the borehole journals as grey and dark grey shales or sandy shales, occasionally including some dolomitic limestone bands. Smith has recorded obscure plant remains from them, and their correlation with the Hilton Plant Beds of Edenside seems now to be generally accepted (Smith, 1924a ; Hollingworth, 1942). Magnesian limestone recorded in the journals usually as "yellow, brown or grey honeycomb limestone" or "decomposed limestone," is found both above and below the Grey Beds. In one hole (No. 2, Fig. 2) four separate bands are recorded, one being 50 feet thick, and in another it is apparently reduced to one or two thin layers only.

The magnesian limestone in Kirksanton No. 6 boring yielded the following Permian fauna, identified by Dr. C. J. Stubblefield :—*Bakevella antiqua* (Munster), *Pleurophorus costatus* (Brown),

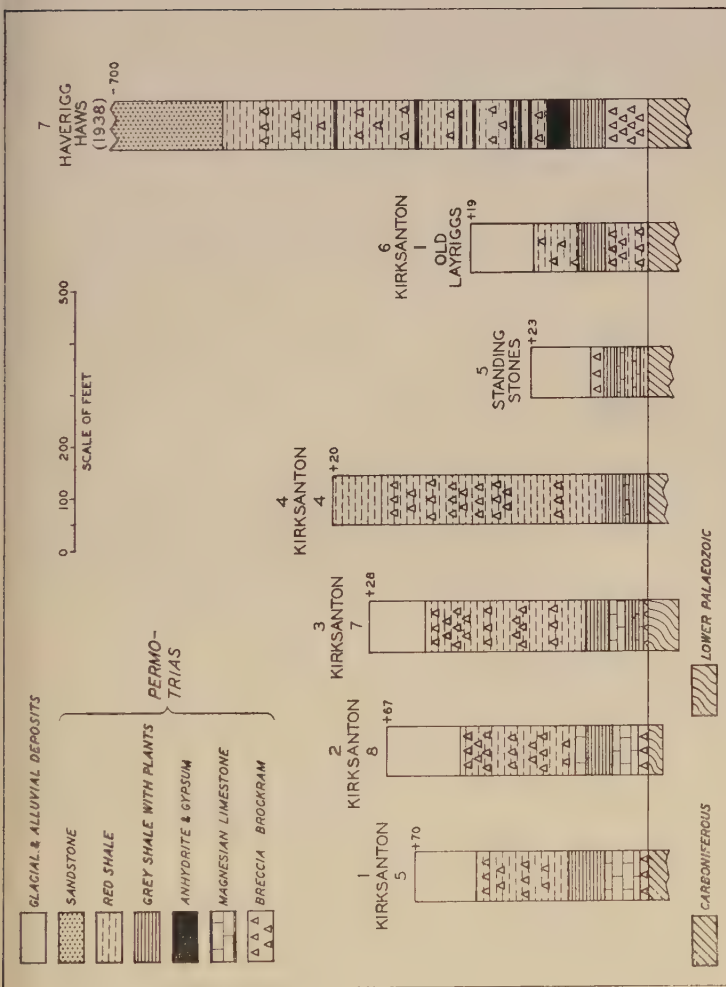


FIG. 2.—SECTIONS OF BOREHOLES IN SOUTH CUMBERLAND, to illustrate the lithological variations in the Kirsanton Beds (Zechstein).

? *Pseudomonotis speluncaria* (Schlotheim), *Schizodus* aff. *truncatus* King, *Schizodus* sp., "*Natica*" *leibnitziana* King, *Turbo*?

The upper part of the Kirksanton Beds is clearly the equivalent of the St. Bees Shales, consisting generally of red shale and sandy shale, containing numerous layers of breccia. There appears to be a tendency for the breccia to be thicker nearer the top (see Nos. 2, 3 and 4, Fig. 2), and in some of the holes continuous records of "limestone breccia," "conglomerate chiefly lime" and "shale with limestone nodules" may indicate massive Brockram beds up to 200 feet thick.

Where the Kirksanton Beds are penetrated by the Haverigg Haws borehole the succession is as follows:—

Kirksanton Beds	St. Bees Sandstone			+600 feet	} 830 feet
	St. Bees Shale and Upper Brockram	....	....	635 feet	
	Anhydrite and gypsum	....	....	40 feet	
	Grey Beds	....	....	65 feet	
	Lower Brockram	....	....	90 feet	

The authors were fortunate in being able to examine the cores of this borehole. It will be noted that the main differences from the Kirksanton area, only about two miles away, are that a well-defined Lower Brockram is present, and that anhydrite and gypsum have taken the place of magnesian limestone. The significance of the latter change has been discussed by Hollingworth (1942). The Lower Brockram is reddish-stained at the base, grey at the top, and made up of angular fragments of Carboniferous Limestone averaging one to two inches in diameter, in a hard, sandy and calcareous matrix. The Grey Beds which succeed are dark grey shales, in places calcareous or dolomitic, and as at Kirksanton contain obscure plant remains, mostly unidentifiable; examination by Dr. R. Crookall revealed, however, the presence of the Permian plant, *Ullmannia bronni* Brogniart. They are overlain by about 100 feet of beds, the lower 40 feet of which is mainly a massive, granular anhydrite, and the upper 60 feet sandy marls with some breccia containing much dolomite and anhydrite. The latter group, although mainly grey in colour, is regarded as forming the lowest beds of the St. Bees Shales, while the solid sulphate appears to be the lateral equivalent of highest magnesian limestone horizon at Kirksanton.

The St. Bees Shales in the Haverigg Haws borehole are taken to be about 635 feet thick, although they pass up gradually into the overlying St. Bees Sandstone and the exact dividing line is uncertain within perhaps 50 feet. Apart from the bottom 60 feet, as mentioned above, the beds are almost uniformly dark red in colour, though with green mottlings in places. Throughout the greater part of the group thin layers of fine breccia or coarse and gritty sandstone are common, and seams and thin bands of gypsum and anhydrite are frequent near the base.

Furness.—Occurrences of Brockram in Furness are confined to the northern margin of the middle block, between Sowerby Wood and the old Goldmire haematite mine. There are no outcrops of Zechstein rocks here, but many borings have explored the area in search of iron ore, and No. 4 Shaft at Thwaite Flat mines, from which the southernmost ore-body on the California Vein was worked, proved 60 feet of Brockram beneath drift deposits. The dump shows the only Brockram at present available for examination in Furness. The breccia consists of angular fragments of limestone suggestive of the Carboniferous Dalton Beds (C_2S_1) and Park Limestone (D_1) in a red sandstone matrix. Representative borings in this region are illustrated in Fig. 3, Nos. 9-11. Farther east, the Brockram passes laterally into St. Bees Shale, for Thwaite Flat Nos. 1 and 2 borings record only red shale resting on Carboniferous (D_2).

Magnesian Limestone is apparently not present at the northernmost margin, but beneath Sowerby Wood it has been proved to be present (Fig. 3, Nos. 10, 12).¹ The Brockram meanwhile thins and dies out to the south between Sowerby Wood Nos. 2, 3 and No. 1 borings.

South of Sowerby Wood there are no further borings deep enough to reach Zechstein deposits for three miles. At Davy Street, Barrow (Fig. 3, No. 16), a boring made by Vivians for Colonel Strongitharm in search of coal in 1902-3 proved the following section :—

DAVY STREET BORING, BARROW²

Surface level 21.25 feet O.D.

	Thickness		Depth	
	Feet	Inches	Feet	Inches
Glacial drift	99	—	99	—
Bunter :				
Red sandstone	2,012	3	2,111	3
Zechstein :				
Red sandy marl and sandstone	23	7	2,134	10
Red conglomerate, marl balls	8	—	2,142	10
Red sandstone and marl	112	2	2,255	—
Red sandstone	21	—	2,276	—
Red marl	20	—	2,296	—
Red marl with gypsum	24	—	2,320	—
Grey and red shale with gypsum and red sandstone	290	—	2,610	—
Gypsum	26	—	2,636	—
Grey shale and red marly gypsum	150	—	2,786	—
Dark grey shale, with fossil leaves and gypsum	4	—	2,790	—

¹ A full journal of Sowerby Wood No. 1 borehole has been published by De Rance (1899).

² The version of this boring given here is based on Vivian's detailed journal down to 2,320 feet (in Geological Survey records) and the journal in *Proc. Barrow Field Nat. Club* (1909) for the rest. The classification is ours.

Carboniferous :	Thickness		Depth	
	Feet	Inches	Feet	Inches
Dark grey shale	39	—	2,829	—
Dark grey fossiliferous limestone	2	—	2,831	—
Grey sandy shale	25	—	2,856	—
Hard fossiliferous sandstone	7	—	2,863	—
Red, blue and green shale	47	—	2,910	—
Red and blue shale and purple rock with ironstone	14	10	2,924	10
Red and brown rock and red sand- stone	—	8	2,925	6
Yellow, red and grey shale	26	6	2,952	—
Grey sandstone	6	—	2,958	—
Red, grey and blue shale	42	—	3,000	—

A comparison of the Zechstein strata in the Sowerby Wood No. 1 and Davy Street borings shows two important features: the Magnesian Limestone, 55 feet 10 inches thick at Sowerby Wood, is presumably represented by the 26 feet bed of massive "gypsum" at Davy Street; and the total thickness of Zechstein strata has increased from 290 feet to 679 feet. At Davy Street almost the whole Zechstein section is of St. Bees Shale facies. Unfortunately the cores of this boring were not retained, so that it is impossible to ascertain whether the massive evaporite layer, recorded in the journal as "gypsum," was in fact composed of this mineral, or of anhydrite. Our experience elsewhere suggests that the latter is more likely.

The Davy Street section mentions grey shale with "fossil leaves and gypsum" at 2,790 feet, and it seems possible that this bed is the equivalent of the Permian plant-bearing shale of the Kirksanton area. Hollingworth (1942) has suggested that the black gypsiferous sandstone beneath the evaporite horizon in Rampside No. 2 boring (below) may represent an arenaceous facies of these beds.

In the eastern block, the Magnesian Limestone crops out at Old Holebeck, but the present exposure is disappointing, only two feet of yellow, porous dolomitic limestone being visible. In Aveline's time (1873, p. 9) there were quarries on both sides of the Stank-Roose road and he estimated that, taking into account a boring put down to the shale which underlies the limestone by Mr. E. Wadham (Bolton, 1869, p. 89), there are 63 feet of yellow cellular limestone here. The western quarry has since that time been filled up to make the Stank mineral railway, while the eastern quarry is now largely obscured by slipped boulder clay.

The present limited exposure yielded only internal and external moulds of *Bakevella antiqua* (Münster), identified by Dr. Stubblefield, who states that he sees nothing either in the fauna from Kirksanton No. 6 boring or from Holebeck diagnostic of an Upper Magnesian Limestone age.

The shale beneath the limestone is stated to be plant-bearing, but it is not known whether these shales belong to the Carboniferous

or represent the grey shales of Kirksanton. Carboniferous shales are, however, certainly present at no great distance below the limestone.

The continuity of the Magnesian Limestone eastward from Old Holebeck has been proved by borings adjacent to the Boggart Bridge-Gleaston road. At Gleaston the following section was proved :—

GLEASTON GREEN No. 3 BORING

Surface level 34 feet O.D.

	Thickness		Depth	
	Feet	Inches	Feet	Inches
Glacial drift	53	6	53	6
? Bunter :				
Red and white sandstone	102	—	155	6
Zechstein :				
Red shale	6	—	161	6
Magnesian Limestone	5	—	166	6
? Carboniferous or Zechstein :				
Blue sandy shale	10	—	176	6
Red sandstone	121	—	297	6
Red sandy shale	45	—	342	6
Red and black shale, alternating (gypsum joints 405–420 feet)	95	6	438	—
Red sandstone and quartzite	19	6	457	6
Fault breccia				
Red sandstone mixed with spar	27	6	485	—
Carboniferous (Gleaston Group) :				
Black and red shale	146	—	631	—
Limestone	7	—	638	—
Shale with limestone bands	16	—	654	—
Black shale, some sandy beds	194	—	848	—

Doubt exists about the correct correlation of the 300 feet of beds below the Magnesian Limestone, in view of the record of gypsum. Allowance is made for the possibility that these belong to the Zechstein by the dotted line north of the Magnesian Limestone outcrop shown in Fig. 1. Similar doubt exists about the following portion of the record of Gleaston No. 4 boring (Fig. 3, No. 14), a full log of which has been published by De Rance (1899) :—

PART OF GLEASTON No. 4 BORING

	Thickness		Depth	
	Feet	Inches	Feet	Inches
[Anhydrite	33	6	594	—
Shale	5	—	599	—
Magnesian Limestone	65	—	664	—]
? Carboniferous or Zechstein :				
Blue sandy shale	64	1	728	1
Conglomerate	2	—	730	1
Red, blue and green shale	21	6	751	7

	Thickness		Depth	
	Feet	Inches	Feet	Inches
Red gritstone, gypsum joint	2	—	753	7
Red and green shale....	26	6	780	1
White sandstone	10	—	790	1
Red and green shale, gypsum joints	39	6	829	7
Pink and grey sandstone	61	6	891	1
Red and blue shale	68	5	959	6
Shale, gypsum joints	17	—	976	6
[Carboniferous			to 2,108	—]

There is also doubt about the measures below the evaporite horizon at Rampside No. 2 boring (Fig. 3, No. 15), which has here entirely taken the place of the Magnesian Limestone; the downward succession being:—Black sandstone and gypsum 42 feet 9 inches; purple shale 18 feet 2 inches (gypsum in lower 9 $\frac{3}{4}$ feet). Pending a modern boring in the area, it does not seem possible to decide; in Fig. 3, Nos. 14, 15, the questionable beds are included with the Carboniferous.

Hollingworth (1942) has already called attention to the striking manner in which massive anhydrite in Rampside No. 2 is represented in Gleaston No. 4 by anhydrite overlying Magnesian Limestone. Still farther north, the evaporite dies out, and Magnesian Limestone alone remains at Gleaston No. 3. There is marked thinning of the Zechstein (i.e. St. Bees Shale) succession above the Limestone from south to north, as in the middle block.

Petrography of Zechstein Sediments and Evaporite.—The following account is based on material from the Haverigg Haws borehole. The Lower Brockram is a breccia predominantly of limestone fragments which reach several inches long, with occasional fragments of mudstone, tuff and lava (E.22434). The matrix may be calcite or less commonly dolomite, enclosing variable amounts of rounded and subangular grains of quartz, rare microcline and nests of pyrite. The overlying Grey Beds (E.22432, 3) are alternations of impure dolomite with dolomitic siltstone, carbonaceous matter, from plants, being present in some abundance. The silty matter is mainly quartz, in angular grains below 0.06 mm. diameter, with white mica, chlorite and opaque grains, in a fine-grained dolomite matrix. Throughout this group, dolomite is the predominant carbonate; in spite of the reducing conditions which must have obtained when it was deposited, no ankerite was formed (as indicated by the absence of carbonates with refractive index n_D above 1.682), the iron appearing as pyrite. Veins of fibrous gypsum are common.

The main evaporite horizon (E.22426-31) includes several lithological types. A nodular variety of anhydrite rock accounts for a considerable part of the bed. In this, lenticular masses of fairly pure anhydrite, up to 10 mm. diameter, in which the crystals may be fine (0.03 mm.) or coarse (up to 0.5 mm.), are surrounded

by films or wisps of dolomite or dolomitic silt with quartz. Rocks of this type also occur in the Permian of Durham and a photomicrograph of a typical example has been published (Dunham, 1948, Plate 10, Fig. 4). In another type thin bands of pure anhydrite alternate with bands carrying dolomite, quartz grains and haematite, the layers showing gentle undulations. Massive grey or white anhydrite, an aggregate of elongate hypautomorphic crystals, also occurs, but no bed more than six inches thick is present. Gypsum, though not common, is present in the main evaporite at Haverigg, where it forms "porphyroblasts," generally considerably larger than the individual anhydrite crystals. These are rarely free from unreplaced relics of anhydrite, which in some examples are arranged in bands, alternating with pure gypsum bands (E.22426). A similar phenomenon, producing zoned porphyroblasts, has been illustrated from Durham (*op. cit. supra*, Fig. 1). Pink gypsum also occurs in what appears to be a band injected into grey micaceous siltstone (E.22428) within the main anhydrite.

Above the main evaporite bed, dolomitic and calcareous siltstones and fine sandstones carry thin beds of anhydrite, some of them nodular (E.22421), others massive (E.22424). Mixed dolomite-anhydrite rocks (E.22423) have a crystalline appearance and consist of automorphic anhydrite crystals up to 0.5 mm. long, with interstitial fine-grained dolomite in rhombs averaging 0.02 mm. across. Anhydrite-calcite rocks also occur (E.22425), the particular example studied showing spherical calcite aggregates about 0.04 mm. diameter scattered through a matrix of anhydrite crystals 0.005 to 0.1 mm. long. These aggregates resemble poorly-developed ooliths.

The clastic sediments of the St. Bees Shale group are for the most part calcareous or dolomitic siltstones, essentially quartz rocks composed of angular grains less than 0.06 mm. diameter, with a carbonate matrix. Muscovite, chlorite and ? hydrobiotite flakes are common, and in the red examples there is a coating of haematite round the grains. Haematite also occurs as rounded granules. Feldspar is extremely rare in these rocks, even in a partly-altered condition, and it seems unlikely that the silt was of local origin, where abundant feldspar might be expected to be available from the Borrowdale lavas and Lake District intrusions.

Green lava fragments are, however, common in the breccias intercalated in the Kirksanton Beds above the main evaporite (E.22417, 22419, 22420, 22422), including albitised, chloritised andesites and felsitic types. Carboniferous Limestone continues to be an important constituent of the breccia bands even in the highest Zechstein beds, over 800 feet above the base of the formation. The Limestone was clearly still exposed at the end of Zechstein times. The matrix of the breccias may either be calcite (e.g. E.22417, 9) or dolomite (E.22422); it may carry quartz grains, and enclose nests or nodules of anhydrite. White, grey and red breccias occur.

BUNTER

South Cumberland.—So far as is known only the lower subdivision of the Bunter (the St. Bees Sandstone) is present, the greatest thickness recorded to date being about 600 feet in the Haverigg Haws borehole. One or two other boreholes between Kirksanton and Haverigg have also entered "red sandstone" or "soft red freestone." Farther north, three boreholes sunk over 50 years ago in the ground lying approximately one mile west of Kirksanton entered red sandstone beneath drift, and provide the evidence for the existence of the north-south fault in this area separating St. Bees Sandstone from Kirksanton Beds.

The lithology of the St. Bees Sandstone calls for no special comment. By diminution in the number and thickness of shale bands, there is a gradual passage upwards from the Kirksanton Beds. In the Haverigg Haws borehole occasional shale bands are found up to 10 feet in thickness; otherwise the rocks are fine red sandstones of the normal St. Bees type.

Furness.—Red sandstones, classified as St. Bees Sandstone, are exposed at intervals along the Vale of Nightshade and in small quarries on Barrow Golf Course, but the best exposure is at Hawcoat quarry, where altogether 148 feet of red sandstone, with occasional persistent thin beds of white sandstone, are visible. At certain levels the bedding is irregular and in places small-scale false-bedding is visible, but for the most part the sandstone breaks in posts (layers) four to six feet thick. Concentrations of micaceous minerals at certain levels are noticeable, clay-galls being associated with some micaceous layers. A boring put down from the bottom of the quarry proved 749 feet 6 inches of red sandstone without reaching the base.

Evidence that Bunter Sandstone extends southwards from the Hawcoat ridge beneath the town of Barrow comes from the Davy Street boring (page 21) and from a number of shallower boreholes. At Ormsgill Reservoir 50 feet 6 inches of "Permian Sandstone" was proved beneath 114 feet of drift. A recent boring (1942) from the Barrow Haematite Co.'s sidings near Whinsfield House ("B" on Fig. 1) entered Keuper Marl beneath 125 feet 9 inches of drift and at 322 feet is believed to have passed through the Boundary Fault between the western and middle blocks, continuing in broken grey sandstone to 393 feet. Notes on the cores from this boring, which were examined for the Geological Survey by the late Mr. A. Templeman, record the presence of traces of petroleum in the brecciated sandstone between 334 and 356 feet. The sandstone is in part calcareous here. In Cavenish Street, 129 feet of sandstone was proved beneath 71 feet of drift deposits. At the Barrow Co-operative Society's dairy, Crellin Street, 161 feet of red sandstone "with an intermediate layer of limestone" beneath 93 feet

of drift is recorded in the borer's journal dated 1929. The "limestone" is presumed to have been calcareous sandstone. Nineteen borings at the Risedales made in 1862-3 proved red sandstone at depths varying from 9 feet 6 inches to 82 feet below surface. At Barrow Paper Mills a test boring and four wells near the southernmost extension of the middle block ("P" on Fig. 1) proved up to 455 feet of red sandstone with some grey layers beneath drift.

In the eastern block the sandstone was proved in an abortive attempt to find coal half a mile north of Rampside. Aveline (1873) gives the journal of the borehole (Rampside No. 1)—abandoned owing to the breaking of the rods—as follows:—Drift 78 feet, Red Sandstone 120 feet, Magnesian Limestone 267 feet, Red Sandstone 290 feet. Aveline was very doubtful of the record of limestone, and his view that the rock was in fact sandstone was vindicated by Rampside No. 2 borehole (Fig. 3, No. 15), which showed 1,102 feet of Bunter Sandstone. The easternmost boring proving St. Bees Sandstone was four to five miles east of the village of Leece, where red sandstone was penetrated beneath 78 feet of boulder clay.

The highest beds of the Bunter were proved in the western block, beneath the Keuper Marl under Walney Island in Walney borings Nos. 1 and 6 (below). Grey sandstones predominated in the 341 feet at the top of the Bunter section in No. 1 boring (Fig. 5, No. 23), underlain by 222 feet of mainly red sandstone, while in No. 6 borehole, of 304 feet of sandstone, all but six feet is recorded as red. The possibility nevertheless remains that these beds are to be correlated with the variable Kirklington Sandstone of north-west Cumberland rather than with the St. Bees Sandstone. Some grey beds, perhaps at a similar horizon, were noted at the Barrow Paper Works.

The maximum thickness of Bunter in any single boring—2,012 feet—is at Davy Street, but this hole is far from the supposed southern margin of the sub-drift outcrop in the middle block. Taking into account the dip recorded in this boring (8°) it appears reasonable to conclude that not less than 2,500 feet of Bunter Sandstone must be present.

Petrography of St. Bees Sandstone.—The typical rock of Hawcoat Quarry (E.17790) is composed of angular grains averaging a little less than 0.1 mm. with subordinate orthoclase, oligoclase, muscovite, chlorite and ? hydrobiotite. Constituents with specific gravity greater than 2.89, totalling only 0.05 per cent by weight, include elongate euhedra and anhedra of zircon, brown, bluish-green and mauve tourmaline, apatite, dolomite, rutile, anatase, "leucoxene," ilmenite and very rare staurolite (E.17759). The rock is partly cemented with secondary silica, but red iron oxide is a far more conspicuous material between the grains. Variations in the haematite-content of the rock give rise to colour-banding parallel

to the bedding, a feature which may be held to show that the haematite is an original constituent of the rock. The sandstone worked at Yarlside Mine for moulding sand (E.17788) is richer in haematite than any of the Hawcoat material, and contains well-rounded quartz grains up to 0.4 mm. diameter in addition to finer angular material. The heavy mineral suite from this locality is similar to that of Hawcoat (E.17711-4), but apatite is not present. A suite like that at Hawcoat, including apatite, was obtained from the sandstone exposed at Furness Abbey (E.17761), while at Millbrow a little garnet was found in addition (E.17760).

The heavy mineral suite, impoverished as regards variety of species present, is similar to that found by Versey (1939) in the St. Bees Sandstone of the Vale of Eden save for the frequent occurrence in Furness of apatite. Garnet is as rare in Furness as in Edenside. A systematic examination of St. Bees Sandstone from west Cumberland undertaken at the time of the Furness investigation, revealed similar conditions there. Samples, supplied by Dr. Trotter, taken every 100 feet from 255 to 1,155 feet in Beckermets No. 36 borehole, and from 180 to 775 feet in No. 38 borehole, showed restricted suites with zircon, tourmaline, rutile, some anatase, ilmenite, "leucoxene," magnetite, very rare garnet, staurolite and amphibole, and persistent (in some separations, abundant) apatite. No significant variation was found in the suites in spite of the considerable range of depths covered.

Analyses of St. Bees Sandstone have given the following results :

			1	2
			<i>Hawcoat Quarry</i>	<i>Yarlside Mine</i>
SiO ₂	....	....	88.63	92.68
Al ₂ O ₃	....	....	3.44	3.74
Fe ₂ O ₃	....	....	3.39	2.26
CaO	....	....	tr.	0.22
MgO	....	....	} 3.72	tr.
Na ₂ O+K ₂ O	....	....		1.0

Analysts : 1 E. Richards (1879) ; 2 G. Williams in *Abbey Sand*, booklet issued by Abbey Sand Co. Ltd., Barrow, 1937.

Relation to Haematite Deposits.—In the neighbourhood of the present northern margin of the Permo-Triassic outcrop in the middle block immediately south of the Roanhead mines, borings near Sandscale Farm prove that the Bunter Sandstone overstepped the Zechstein deposits to rest directly upon the Carboniferous. At the Roanhead and Park mines, and also on the south-eastern flank of the High Haume anticline, north of Dalton, the remarkable haematite ore-bodies known as sops have been worked. These are essentially hollows in the Carboniferous Limestone, having the general shape of inverted cones, lined with high-quality haematite ore. The larger examples—Rita and Nigel sops at Roanhead, the great Park sop, the California sops and a few of the small sops north-north-east of Dalton—were found to have central cores of red,

less commonly white, sandstone. Examination during the re-survey of levels driven through the Nigel and California sops showed that the cores consist of a breccia of great blocks of sandstone identical in appearance with the normal St. Bees Sandstone. It is notable, however, that nothing comparable with the Brockram, Magnesian Limestone or St. Bees Shale has been found in the cores, unless the relatively small quantity of "red muck" recorded in some workings represents broken-up shale.

Sections of typical sops are given in Fig. 3 (Rita) and Fig. 4 (Nigel). The latter exemplifies in detail the various linings of the sops, which extend to 600 feet below sea level. The limestone walls are obviously water-worn and show a white "decalcified" skin. A cave-breccia known at Roanhead as the "rubble" follows; it is composed of large, rounded limestone boulders also showing white skins, in a matrix of brown clay. The white skin apparently results from partial solution of CaCO_3 , but the composition of skin and adjacent limestone differs little, as shown by the following chemical analyses, kindly made by Mr. G. Williams on a specimen from Roanhead:—

	<i>Unaltered limestone</i>			<i>White skin</i>
CaO			55.01	53.97
MgO			0.60	0.36
Fe_2O_3			tr.	0.30
SiO_2			1.62	2.83
Al_2O_3			0.51	0.46
CO_2			42.68	41.86
SO_3			tr.	tr.
			100.42	99.78

It must be emphasised that the rubble is quite different from Brockram (1) in the shape of the boulders; (2) in the presence of white skins on the boulders; (3) in having a clay matrix. Red clay (the "casing"), up to 10 feet thick, separates breccia from ore. This layer shows marked slickensides, generally vertically striated on the steep sides of the sop. The ore is haematite, invariably (as far as our experience goes) broken up into fragments, in a matrix of powdery material of the same composition. Finally comes the central core of sandstone blocks.

The first conclusion to be drawn is that the St. Bees Sandstone in the area of the sops rested directly on the Carboniferous Limestone, with little or no intervening Zechstein. Binney (1847) and Murchison and Harkness (1864) believed that the ore was formed prior to the Permian sediments, but in view of the clear relationship of the haematite mineralisation to post-Triassic faults here, as in west Cumberland, and the absence of post-mineralisation faulting we cannot subscribe to this view. Smith (1924b, p. 39) has suggested that swallow-holes formed in pre-Triassic times were mineralised after the deposition of the New Red Sandstone. Had this been

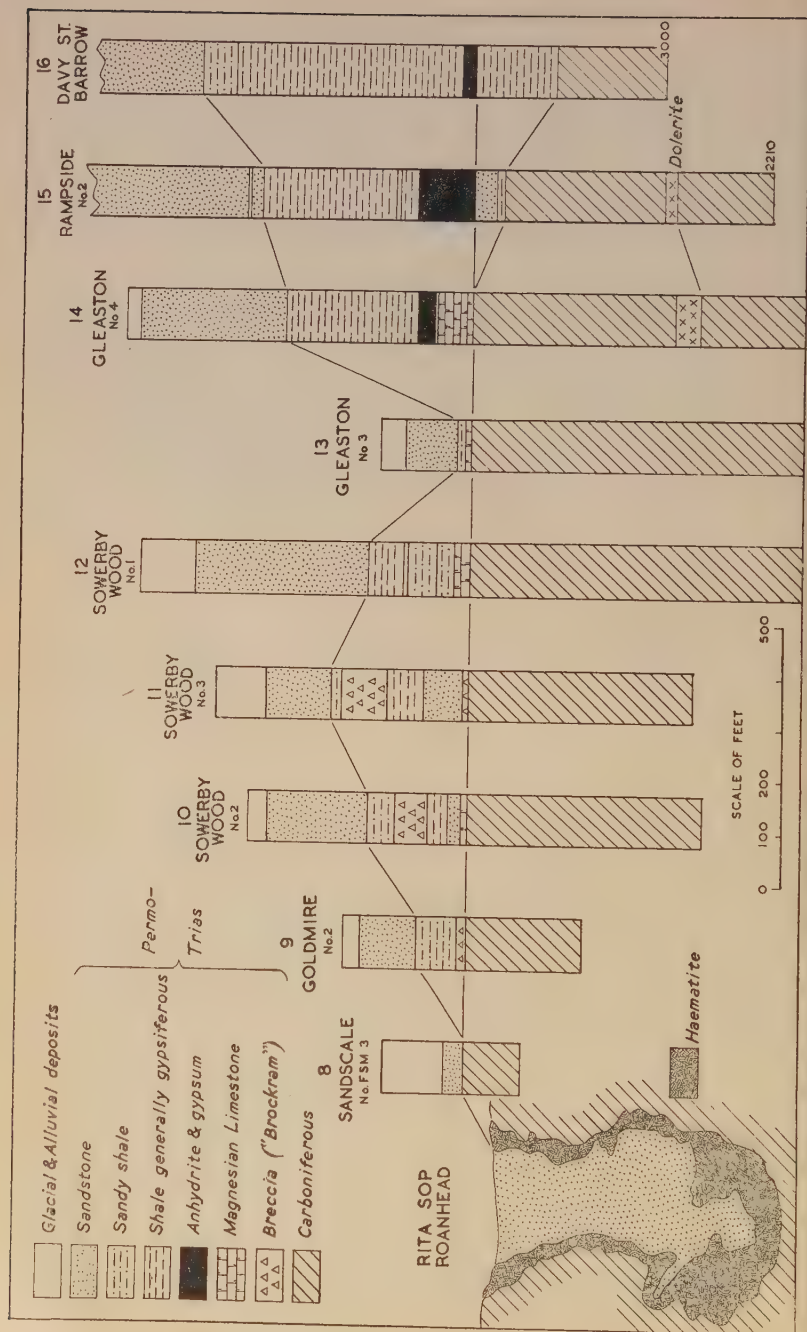


FIG. 3.—SECTION OF THE RITA SOP ROANHEAD, and environs, of the Permian and Carboniferous.

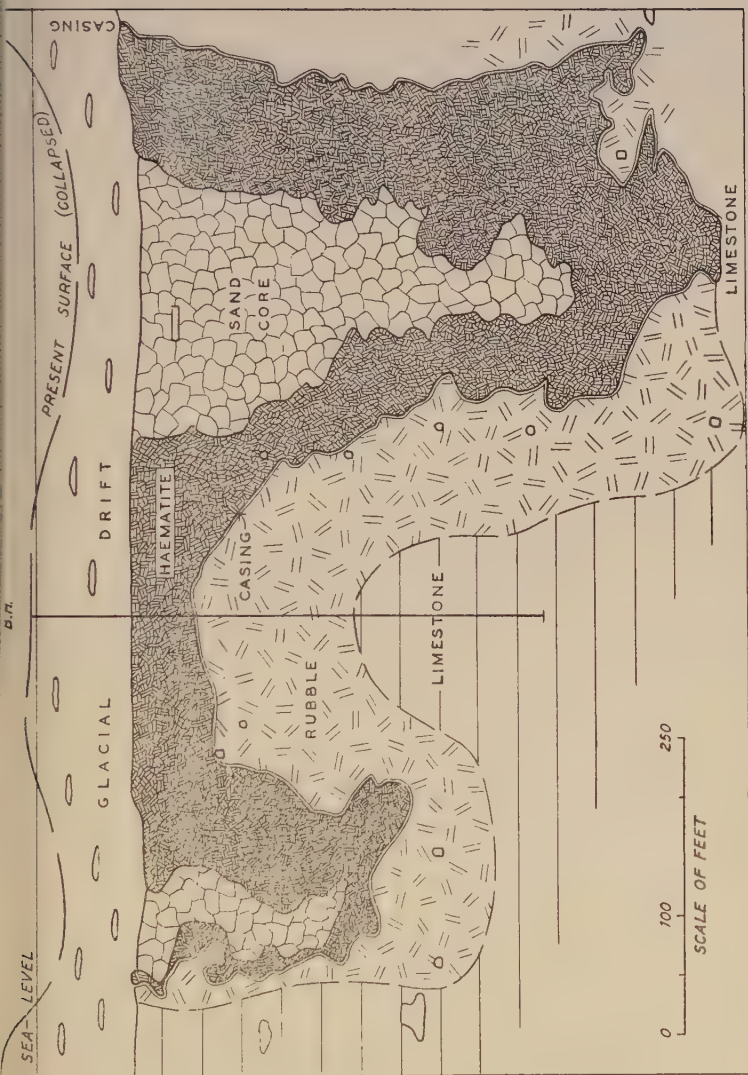


FIG. 4.—LONGITUDINAL SECTION (WEST-NORTH-WEST—EAST-SOUTH-EAST) THROUGH NIGEL SOP,
ROANHEAD MINES.

the case, the sand cores would not be in the form of a breccia of blocks of consolidated St. Bees Sandstone. It is therefore suggested that the sops originated as swallow-holes produced by waters circulating from the sandstone into the limestone, like those beneath Millstone Grit sandstone, for example, at Simonseat in Yorkshire. Presumably this could only occur when the water-table was low down in the limestone. Most probably the iron was introduced into the sops, which must have focused the flow of underground water upon relatively few channels, by solutions from the sandstone, but whether the iron was derived from the ferruginous cement of the St. Bees Sandstone as Smith (1928) suggested, or was contributed to the waters in the sandstone from hydrothermal veins as Dixon (1928) and Trotter (1945) advocate, we are unable to say. It might be argued that a period of solution without mineralisation was necessary to form the "rubble." It is suggested, however, that this period may have been subsequent to the mineralisation, not only forming cave-breccia, but causing the collapse of the haematite, and breaking it up. On this view the "casing" represents the clay-matrix of the rubble, mixed with powdered haematite. The downward movement of the broken-up haematite in the sops would also lead to further collapse of the red sandstone into the core. If this view of the origin of the sops is correct, they would not be formed where the St. Bees Shale is present, and it may be added that in spite of numerous borings through the "New Red" cover, no sops have been found beneath St. Bees Shale. The dip of the Carboniferous rock is, moreover, such that the Gleaston Group, also containing a high proportion of shale, intervenes between the "New Red" and the potentially productive limestone immediately south of the Sowerby Wood-Goldmire line and south of Yarlside Mine.

In the eastern block the belt of sops north and east of Dalton is succeeded to the south by a belt of veins without sops. These veins may well have been formed beneath Gleaston Group (Yoredale) cover (*vide* Smith, 1924b, Plate 3), but Gleaston No. 3 boring suggests that the overstep of the Bunter on to the Carboniferous occurred considerably farther south in this block than in the middle block.

On the haematite mineralisation we are thus in accord with the principal authors on the west Cumberland ore-field in believing that the St. Bees Sandstone acted as a reservoir of ferriferous waters from which the Carboniferous Limestone was mineralised. Furness offers clear evidence of a direct connection between the sub-Bunter surface and the sops. The veins and flats of the district were found—where any evidence is available—at places permitting free access of waters from the sandstone. The mineralisation must have occurred after the erosion of part, but not all, of the Bunter,

at a time when general elevation or dry climate produced a water-table much below that existing at present.

It is interesting to note that although apatite is a common minor constituent of the St. Bees Sandstone, it is absent from the heavy mineral suites—otherwise quite normal—of the sandstone from the cores of the Nigel and California sops and also near the Yarlside fault (E.17705-6, 17707-10, 17786, 7). Possibly it has been dissolved out by the intense flow of waters which may well have been acid in composition; and, if this is the case, a source of fluorine to form fluorite (known only as pseudomorphs in haematite in the present district, but not uncommon in west Cumberland) is suggested.

KEUPER

Walney Island.—Keuper Marl was first encountered beneath Walney Island in a boring at the extreme southern end of the island, made in 1887 by the Walney Exploration Co., once again in search of a possible coalfield.¹ The following is an abstract of the journal:

WALNEY No. 1 BOREHOLE

Surface level 20 feet O.D.

	Thickness		Depth	
	Feet	Inches	Feet	Inches
Raised Beach	45	—	45	—
Glacial drift	97	—	142	—
Keuper :				
Red, grey and blue shale and marl with gypsum	361	—	503	—
Red spongy shale with salt	15	—	518	—
Red, grey, green and blue shale and marl with gypsum	889	—	1,407	—
Bunter :				
Grey sandstone	148	—	1,555	—
Red sandy shale	3	6	1,558	6
Grey sandstone	256	6	1,815	—
Red and reddish-grey sandstone ("like St. Bees")	222	—	2,037	—

A series of three borings (Nos. 2-4; see Fig. 5) in the vicinity of Biggar, which followed in 1888, proved the presence of thick beds of rock salt, thinning somewhat to the south. The deposits provided brine for a short-lived salt industry.² Four wells were drilled between Nos. 3 and 4 borings, and the brine was pumped to a reservoir, whence it gravitated to a salt-works at the extreme southern end of the island. Residues from the old brine pans contain coarse gypsum, enclosing fine-grained anhydrite and clay-material (E.18592-5). That calcium sulphate is the main impurity in the

¹ *Barrow News*, 17th November, 1888.

² Some of the production of salt from Lancashire, all attributed to the Preesall district in the *Salt Memoir* (Sherlock, 1921, p. 79) presumably came from Walney.

Walney rock salt is indicated by the following analyses, quoted from reports in the Buccleugh Estate Office records :—

	1	2	3
NaCl	98.90	96.67	98.93
CaCl ₂	0.08	Nil	Nil
MgCl ₂	0.11	0.34	0.15
CaSO ₄	0.38	2.20	0.10
Fe ₂ O ₃	Nil	0.06	0.06
Al ₂ O ₃	Tr. }		
Insol. in H ₂ O	0.36	0.48	0.56

Analyses : 1 R. Hellon ; 2 and 3 A. Norman Tate and Co. Dated 1895.

The salt deposits around Biggar were not, however, the thickest proved beneath Walney, for No. 5 borehole, 1,100 feet north of the Crown Inn, North Scale, a record of which has previously been published (Sherlock, 1921, p. 80) proved at least 237 feet of rock salt. Another boring has recently (1941) been made by the Barrow Haematite Co. near No. 5 hole proving Glacial drift 198 feet 6 inches ; red and grey marl with gypsum 253 feet 7 inches ; Rock salt, 9 feet 1 inch. The gypsum occurs as fibrous bands, rarely up to three inches thick, chiefly at three levels, 243-258 feet, 370-375 feet, and 407-419 feet. Elsewhere it is in the form of balls or grains. A sample of the salt was examined spectrographically by Dr. J. A. C. McClelland for potash, but only 0.03 per cent K was found (Geological Survey Lab., No. 1326, 1943), with Mg 0.15 ; Ba trace ; Sr 0.005 ; B trace ; Rb, C probably less than 0.01.

Marked variation in the depth to the top of the rock salt is shown in the 300 feet between the recent boring and Walney No. 5 is shown. Still farther north, Walney No. 6 failed to find any massive rock salt :—

WALNEY No. 6 BOREHOLE

Surface 30 feet O.D.

		Thickness			Depth	
		Feet	Inches		Feet	Inches
Sand, peat and marine warp	....	40	—		40	—
Glacial drift	....	165	—		205	—
<i>Keuper :</i>						
Red and blue marl with gypsum	....	306	—		511	—
Red marl with salt	....	35	—		546	—
Red and blue marl	....	21	—		567	—
Red marl containing salt	....	16	—		583	—
Red shaly sandstone, shale and marl with gypsum	....	660	—		1,243	—
<i>Bunter :</i>						
Red sandstone	....	51	—		1,294	—
Grey sandstone	....	6	—		1,300	—
Red sandstone	....	247	—		1,547	—

An attempt to assess the relations between the salt deposits beneath Walney Island is illustrated in Fig. 6. The dip of the top

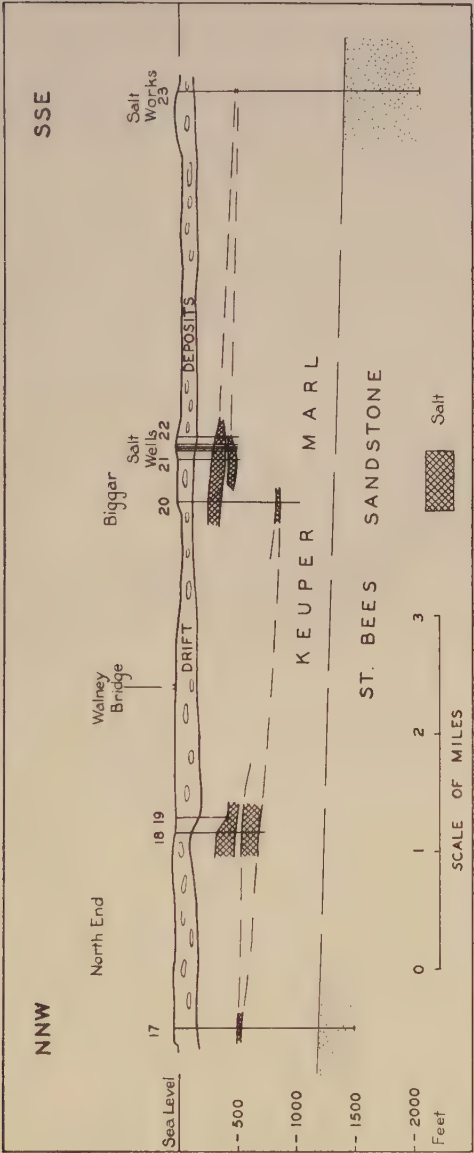


FIG. 6.—LONGITUDINAL SECTION THROUGH WALNEY ISLAND showing the simplest interpretation of the geology.

of the Bunter between Nos. 6 and 1 borings is consistent with that in the Zechstein of the middle block and it seems most probable that no major fault lies between these borings. If, however, this is the case, the salt proved in No. 5 boring cannot be even approximately the same stratigraphical horizon as the deposits of the Biggar neighbourhood. The simplest explanation is, therefore, that two quite separate lenses of salt exist here, the northern perhaps thinning away to the salt-bearing marl of No. 6 borehole, the southern probably represented by the shale with salt at 503-518 feet in No. 1 borehole. It must be emphasised, however, that the evidence is far from sufficient to substantiate this interpretation, or to indicate in what ways the salt deposits may have been modified by solution or by flow under tectonic pressure.

It is assumed that Keuper will overlies the Bunter south of Cavendish Dock in the middle block, but this has yet to be proved.

Comparison with other areas.—Thick salt beds occur in the Keuper Marl on the south side of Morecambe Bay at Preesall, near Fleetwood, where Sherlock (1921, p. 72) has interpreted the evidence from borings as indicating that the deposits are lenticular in form. The structural position resembles that at Walney in lying immediately west of the supposed continuation of the Cumberland Boundary Fault. Below Point of Ayre, Isle of Man (Lamplugh, 1903; Gregory, 1920), numerous thin salt beds occur immediately above the supposed base of the Keuper Marl, while the stratigraphical position of the thick halite deposits in Antrim (Hull, 1876) is apparently lower than those of Walney. The published information on these areas is not, however, sufficient to prove whether the salt beds are subject to primary variations in horizon (which would make them unreliable as markers for more than very local correlation); nor is it sufficient to indicate how much the deposits have been modified by faulting, flow or solution.

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DISCUSSION

MR. EASTWOOD said that from the lucid presentation of the paper the hearers might presume that it had been relatively easy to disentangle the evidence on which it is based. This is not the case, for many borings made by different people at various times are involved, and the records were by borers not geologists, save in very few instances. The late Dr. Bernard Smith was interested in the area for and from the preparation of the Haematite memoir, but the area was not examined in detail until it was resurveyed by the authors. Their terms of

reference were to study the distribution of iron ore, and map the containing limestone and the cover rocks. To do this they were to examine every mine plan and boring in existence. Some of the results of this work were before the meeting and the authors are to be complimented thereon.

The authors had drawn attention to variations in the Permo-Triassic strata beneath the St. Bees Sandstone. Variations as great obtained farther north, where, on the north side of St. Bees Head, St. Bees Sandstone rested on a considerable thickness of St. Bees Shales, with gypsum near the base, and these on 30-40 feet of Magnesian Limestone with just a few feet of Brockram intervening to the Carboniferous. A few miles away, in the Egremont area, the Brockram was 300 or 400 feet thick and there was no development of shales or limestones though these were interdigitated with Brockram in the intervening area.

This indicated that here again as in south Cumberland and Furness there was a narrow belt of rapidly changing deposition bordering the "sea" in which gypsum was deposited, and at a later stage salt.

He noted that the authors believed the salt of Walney Island to be in two or more lenses and not confined to one bed; from this we might infer that salt horizons are not necessarily trustworthy datum planes; for example, salt at Barrow was some hundreds of feet above the base of the Keuper Marl, it was as much as 1,500 feet or more in the Cheshire areas and yet around Stafford was near the base of the Keuper Marl.

PROFESSOR HOLLINGWORTH said that he wished to mention two aspects of the question of facies change which, as the authors fully realised, had such an important bearing on the problems of the stratigraphy of these Red Beds and Evaporites.

The first concerned the horizon of the Keuper Salt beds which had already been commented upon by his old chief, Mr. Eastwood. The speaker's approach was from a rather different angle. The authors had suggested that the salt occurred at several horizons over a substantial range of thickness in the Keuper Marl—an important point, stratigraphically and economically. He had wondered in listening to the paper whether a rather large scale facies change in the associated strata would not provide a possible alternative explanation of the facts.

The authors' datum line in their horizontal section through Walney was the Bunter Sandstone-Keuper Marl boundary. Now there was ample evidence in this area (as the authors have so clearly shown) and elsewhere, that in passing from the margin towards the central parts of a depositional basin, lithological boundaries were often strongly diachronous. Thus a marl-on-sandstone boundary might be expected to occupy a progressively lower stratigraphical level in passing away from the marginal region. If the salt beds were confined to one belt of strata of moderate thickness they could appear quite near the base of the Keuper Marl in the marginal areas, e.g., the Isle of Man, be at an increasing distance above in passing down the length of Walney Island, while in the Midlands as indicated by Mr. Eastwood they would be a long distance above the base in the central (Cheshire) part of the basin and not so far above in Staffordshire. This suggestion was not more than an impromptu one and had perhaps already been considered by the authors. One should bear in mind that the deposition of salt implied a cessation of terrigenous sedimentation coupled with high evaporation and that it seemed a simpler story if this happened broadly simultaneously over a wide region than that it should occur independently in various places at various times.

The second point concerned the possible application of facies change to the significance of the fauna obtained by the authors from the Magnesian Limestone of south Cumberland and Furness. It resembled that of Barrowmouth in having no forms indicative of Upper Magnesian Limestone. As he had long felt concerning the Barrowmouth occurrence, it seemed doubtful whether this meant more than a "faeces fauna." In that case one would not be justified in using it as an argument opposing the equivalence of these limestone to the

Upper Magnesian Limestone which was strongly suggested by detailed consideration of the sequence and facies variation. In Durham the faunal succession of the main Magnesian Limestone was one of progressive impoverishment and dwarfing attributed to increasingly adverse conditions—very probably increasing salinity. It was widely recognised, however, that in enclosed saline basins the shallow marginal areas were often much less saline than the more central regions. This might well lead to the dying out of faunal elements in the central region while they were still able to survive into stratigraphically higher levels in the less saline more marginal areas.

Finally the speaker wished to thank the authors for their permission, readily given some years ago, to make use of some of their facts in one of his own papers. The fear that he might be skimming off some of the cream of their work was evidently unfounded—he had merely taken off a little of the froth from what those present would agree had been very good liquor !

PROFESSOR F. W. SHOTTON expressed the enjoyment with which he had listened to the paper. From what he had seen of the succession in west Cumberland and from the authors' description of the area considered that night, it appeared that one of the great differences between the Permian of the west flank of the Lake District and that of the eastern side, in the Eden Valley, was the complete absence in the former of the dune sands so massively represented by the Penrith Sandstone of the Eden.

Some years ago he had interested himself in the palaeogeography of the Magnesian Limestone sea at its maximum extent and had come to the conclusion that the only satisfactory connection between the Irish deposits and those of northern England was via a strait which crossed the south end of the Furness district. He, therefore, asked the authors if their work led to the same conclusion.

The use of the Hilton Plant Bed facies as a basis of correlation seemed to him subject to objection if applied rigidly. The facies preceded the dolomites at Hilton, but occurred both before and after the Magnesian Limestone of Furness. It appeared possible that these grey shales with plant débris represented moist and non-oxidising conditions which bordered the advancing and at times the retreating Zechstein sea and could occur at different times according to the position which the Zechstein sea had reached.

The haematite sops were of fascinating interest. They recalled the deep pockets of sand, clay and gravel (variously claimed as Triassic and Tertiary) which occurred in the Carboniferous Limestone of west Derbyshire. In such cases of the latter as he had seen the steeply dipping sands, obviously let down by subsidence into the pockets, were separated from the limestone walls by a mass of broken chert in a clay matrix. This, which appeared to be a residual deposit of weathering like the Clay-with-flints of chalk country, suggested a long period of post-Carboniferous weathering before the pockets had been formed. A rather similar clay formation, but in this case containing limestone blocks, separated the haematite of the sops from their walls. The speaker wondered if the formation of the sops could entirely post-date the haematisation, making the ore deposits thus to be collapsed flats.

In a written communication DR. STUBBLEFIELD stated that he understood that Professor Hollingworth considered that the north of England Permian formed a single area of deposition with its western fringe in Northern Ireland. Furthermore, that in Professor Hollingworth's opinion, west of the Pennines the various occurrences of fossiliferous Magnesian Limestone should be interpreted as of Upper rather than of Lower Magnesian Limestone age. An inherent palaeontological difficulty in this matter was that the Upper Zechstein fauna appeared to comprise surviving species of that of the Lower Zechstein with the only appreciable new entrant being the problematical *Filograna ? permiana* King and in the writer's opinion with less certainty as to its "newness," *Schizodus schlottheimi*. This background explained Dr. Stubblefield's

statement in the paper that no species diagnostic of Upper Magnesian Limestone had been recognised in the faunas submitted. He offered two factual observations for Professor Hollingworth's consideration. The first dealt with the presence of *Productus (Horridonia) horridus* in the Cultra Magnesian Limestone of co. Down. Nowhere in the British-German basin had brachiopods been recorded as surviving into the Upper Zechstein seas; therefore, whatever the age of the Lancashire and Cumberland Magnesian Limestone, if the *P. horridus* record was reliable, the co. Down fauna should continue to be regarded as of Lower Zechstein age, unless a concept of anomalous survival such as Professor Hollingworth proposed in his penultimate paragraph was to be invoked.

The second point was the age of the Manchester Marls. This deposit was regarded by King and Geinitz as being of Upper Zechstein age. In 1889 the latter recorded the presence of some needle-shaped tubes at Ardwick and Belle Vue Gardens and at Stockport which he named with some hesitation *Filograna permiana*. Sherlock did not accept this age determination in which respect he was followed by Dr. Versey. The writer had not seen these specimens of supposed *Filograna permiana* but if that could be proved to be present in the Manchester Marls, from his experience of the distribution of that species he would favour the acceptance of an Upper Zechstein age for the Manchester Marls and he would concede to Professor Hollingworth that the non-persistence of the genus *Bakevella* into the Upper Zechstein of Durham had no bearing on age determinations from collections made west of the Pennines. It was well known that *Bakevella* persisted into the Upper Zechstein in parts of Germany.

DR. DUNHAM, replying for the authors, thanked the Association for its kind reception of the paper. The comparison between the salt horizons of Cheshire and Staffordshire mentioned by Mr. Eastwood appeared to favour the view that the salt basins were local rather than regional. In the case of Walney the possibility of diachronous change of facies at the top of the Bunter, as suggested by Professor Hollingworth, had been carefully considered, but had been rejected on the grounds that the dip between Nos. 6 and 1 boreholes on the assumption of little or no diachronism was consistent with the proved dip of the Permo-Triassic rocks on the mainland, and with the position of the base of the sandstone at Haverigg. Professor Hollingworth's correlation of the salt beds would necessitate a northward dip of the top of the salt between Biggar and No. 5 boring, and it failed to explain the two salt horizons, separated by 500 feet of marl, in No. 2 boring. The authors recognised, however, that more than six widely-spaced borings would be needed to settle this point.

In reply to Professor Shotton, nothing comparable with the perfect rounding of the sand grains in the Penrith Sandstone had been found in the Bunter Sandstone of the present area, though a proportion of well-rounded grains were present in the sandstone at Yarlside Mine. The authors would agree with his suggestion as to the palaeogeography of Zechstein times. In Furness and south Cumberland, the distribution of beds of Hilton Plant Beds facies seemed to be markedly irregular, and these beds might, as Professor Shotton suggested, merely be a facies. Evidence was presented in the paper of the downward movement of the broken-up ore in the sops but the authors believed that these bodies had had the form of swallow-holes in the first case. If they had started as bedded replacements, for example, it would be difficult to conceive how the funnel-shaped depression had been formed precisely below each flat.

FIELD MEETING TO STUDY THE COASTLINE OF ROMNEY MARSH

Sunday, 4th July, 1948

Report by the Director : T. W. Marsh, B.Sc., A.M.I.C.E., F.G.S.

[Received 20th July, 1948]

AFTER an interval of half a century [10]* the Association again visited part of Romney Marsh, a party of 17 members and friends meeting at Folkestone on Sunday, 4th July.

The party was conveyed by coach, and a brief halt was made on the Leas to look at the often photographed example of accretion due to an obstruction preventing the free drift of shingle. Here the western arm of the harbour, built in the middle of the last century, has retained about a dozen acres of shingle.

The next halt was made on the Sandgate beach to explain the process of shingle drifting by wave action [6]. This beach was specially chosen, as it was here, in the winter of 1833-4, that Palmer made his observations leading to the first published work on this subject [7]. The problem of coast erosion and sea defence works was mentioned, with reference to the respective parts played by sea-walls and by groynes. Attention was called to the new vertical sea wall with its attendant groynes.

After passing through the old Cinque Port of Hythe an ascent of the Lower Greensand escarpment was made to Shipway Cross. Here a stop was made for a general view over the hundred square miles of marsh and an explanation given of its formation behind a protective shingle beach. The party, descending on to the marsh and crossing the Royal Military Canal, noted the blown sand at Sandtun [1 and 2], and saw on the hillside the slipped walls of the Roman remains of Stutfall Castle. The possibility of a former mouth of the Rother occurring here was mentioned.

After following one of the drainage channels to the Grand Redoubt, the party left the coach and walked along the well-known Dymchurch sea wall, with its sloping stone pitching on a clay bank and low Case groynes retaining sand near low-water mark [3].

After lunch in Dymchurch the road was taken to New Romney (also formerly a Cinque Port) and Lydd. For most of the way this road follows an overgrown shingle ridge and near Lydd a stop was made to examine the material in this ridge. The Director explained that the Rhee Wall (just west of New Romney and running northwards to Appledore) was a channel of the Rother until its diversion in the 13th century by the storms which destroyed the old Winchelsea.

* For list of References, see p. 43.

Continuing through Lydd and by the artillery range (which gave the name Lyddite to the explosive) the edge of the shingle mass was traversed for three miles to Jury's Gut. As the name "Gut" indicates, this is a drainage channel, and a sluice (one of several on the marsh) here allows the drainage of the low land at low tide. A strong wind and driving rain prevented as much being seen as had been hoped; Fairlight was not visible, the present mouth of the Rother could just be made out, Camber sand dunes were visible, and the strong wind was blowing sand from the freshly exposed foreshore at low water. It had been hoped that Fairlight would be visible, as this headland formed the point from which the ridge of shingle left the mainland to enclose the area now occupied by the marsh.

The party then returned to Lydd and turned to Dungeness Point. As soon as the main shingle mass was reached, near the water tower, a halt was made and a short walk taken on the barren ridged shingle, which here extends nearly two miles north, east and south. It had been hoped that some members would have been able to walk across the two miles of shingle to the lighthouse, but the rain prevented this, and the whole party went to the Ness in the coach. Near the Ness a derelict war-time obstruction tower was ascended to see the shingle "fulls" curving approximately parallel to the coast as plotted by Drew on the geological map [9]. When the party arrived here it was low water: some large in-coming oblique waves displayed the process of shingle drifting described at the early halt on the Sandgate beach.

The century-old problem of Dungeness was described. Why should this loose mass of millions of tons of shingle project several miles out into the deep waters of the stormy channel? Early explanations of "tidal currents" and "meeting of the tides" (from North Sea and English Channel) were referred to, and shown to be unsatisfactory. The various papers by Elliott [3], Redman [8] and Gulliver [4] were mentioned, together with the recent one by Lewis [5]. The latter calls attention to the long exposures ("fetches") to the south-west and to the east-north-east, and to the small fetch to the south-east, and maps were produced to show these. The Ness is formed by wave action caused by the winds on these two dominant fetches, and the "meeting of the tides" explanation must be replaced by the "meeting of the fetches."

Leaving the Ness, the coach took the coast road to Littlestone. The well-defined straight parallel ridges on this side of the foreland were pointed out and the sand dunes at Great Stone noted. A stop was made at Littlestone, which was a mouth of the Rother when the river followed the Rhee wall, and it was mentioned that when the Association visited here in 1886 "the site of the old harbour was clearly visible." The inlet formed by this harbour, "Romney Hoy," was until very recently shown on many maps.

The party returned to Dymchurch and took tea at "The Smugglers." A vote of thanks to the Director was proposed by Mr. Stebbing, a past president. After tea the direct road was taken back to Folkestone, a short stop being made in passing the shingle mass at the Hythe, and attention was called to many of the fulls being at an angle to the present coastline. Most of the party returned to London on the 7.18 train. Miss Margaret Marsh acted as secretary of the meeting.

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FIELD MEETING IN THE WORTHING DISTRICT

Sunday, 18th July, 1948

Report by the Director : E. C. Martin, O.B.E., B.Sc., F.G.S.

[Received 15th October, 1948]

THE main object of this meeting, which was attended by 25 members and friends, was to examine some sections in the Littlehampton Anticline and Chichester Syncline in the Coastal Plain west of Worthing. The topographical features of the adjacent area of the South Downs also received attention, and the opportunity was taken of descending a Neolithic Flint Mine recently excavated on Church Hill, Findon.

The Littlehampton Anticline is responsible for a large inlier of Middle and Upper Chalk which underlies the 15-feet Raised Beach and other Pleistocene deposits of the Coastal Plain for some 17 miles west of Worthing [3].* Between this Chalk inlier and the main Chalk outcrop of the South Downs, a belt of infolded Eocene strata has been preserved along the axis of the Chichester Syncline.

Starting at 11 a.m. from Goring-by-Sea Station, which lies a little to the north of the axis of the Anticline, the party crossed the fields and climbed the southern slope of Highdown Hill. The first halt was made in the chalk pit due south of the Camp on the summit (Mr. Gaster's Pit 31 [1]), which shows about 40 feet of chalk in the *Uintacrinus* Band of the *Marsupites* zone, dipping northwards at about 30°. This pit, like all the other pits on Highdown Hill, is in the northern limb of the Anticline.

After leaving this pit, the party walked westwards along the side of the hill to the chalk pits at the top of Hangleton Lane. The western pit, Pit 29, was first visited ; a small working on the south side shows fairly fossiliferous chalk of the *Uintacrinus* band, but the main part of the pit is in the *Marsupites* band. Unfortunately this part has recently served as a dump for the barbed wire used in the war-time defences of the hill, and only the western end, showing the upper beds of the zone, with *Marsupites* plates and *Terebratulina rowei*, is now approachable. From the lowest beds exposed, the Director recently obtained two specimens of *Actinocamax granulatus*, which has not previously been recorded from the *Marsupites* zone in the Worthing District.

Pit 30, on the east side of Hangleton Lane, was next visited. The beds now exposed here are the basement beds of the zone of *Offaster pilula*, with *Echinocorys scutatus* var. *tectiformis* Brydone.

* For list of References, see p. 47.

The chalk in this pit is much disturbed, some of the surfaces showing slickensiding, and is traversed by numerous bands of flint at all angles up to the vertical.

The next halt was made at the Early Iron Age Camp which crowns the summit of the hill (269 feet O.D.), from which a good view of the Coastal Plain and of the Downs to the north was obtained. It was pointed out that for a distance of seven miles along the axis of the Anticline the whole of the Upper Chalk, which is about 800 feet thick in this district, has been removed, and Highdown Hill is the surviving fragment of a range of Chalk downs which at one time must have extended westwards from Worthing to the neighbourhood of the River Arun [3]. The destruction of the rest of this range was presumably effected, or at least completed, at the period of the 15-feet Raised Beach, which has been recognised in several places near the foot of the hill [2].

The highest beds of chalk exposed on Highdown Hill, in the zone of *Actinocamax quadratus*, are seen in Pit 32, on the east side of the Camp. This pit now consists mainly of talus, but beds of chalk, dipping steeply to the north, can still be seen above the talus on the north side of the pit. It was noted in passing, and the party then descended the north side of the hill by way of Pot Lane, passing through Goring Woods across the outcrop of the Reading Beds and London Clay preserved in the Chichester Syncline. There are no exposures of the steeply-dipping beds on the south side of the axis of the Syncline, but on the north side the Basement Bed of the London Clay, consisting of a compact mass of well-rounded flint pebbles, mostly under one inch in diameter, was seen in a small section west of the footpath, about 100 yards south of the brickyard of the Clapham Common Brick and Tile Company. The President remarked on the resemblance of this bed to the Blackheath Beds of the London district, and it is interesting to note that the bed is mapped as "Oldhaven Beds" on the six-inch geological map in the library of the Geological Survey.

The party then moved into the pit adjoining the brickyard, which shows a good section in mottled red and bluish clays of typical Reading facies, but the sandy beds at the top, containing ferruginous nodules with sharks' teeth and *Discinisca ferroviae* Muir-Wood, which were seen by the Association in 1938 [4], are no longer clearly exposed.

After lunch at the Horse and Groom Inn, the party followed the road through Patching on to the Downs, the next halt being made in Mr. Gaster's Pit 21 on Patching Hill. The west end of this pit was used as a dump for chalk from lower horizons when digging a new well at the pumping station in the valley below, but the rest of the pit is still available, and affords one of the most fossiliferous sections in the zone of *Actinocamax quadratus*, as restricted by Mr. Gaster [1],

to be found in the district. The most characteristic fossil of the restricted zone is *Saccocoma cretacea* Bather, specimens of which from this pit were exhibited by the Director; owing to its small size this crinoid, although common, is not easily obtained except by washing.

From Patching Hill the party crossed the valley to Clapham, and followed the footpath through Clapham Woods to Church Hill, Findon. The later part of the walk gave good views of one of the most remarkable of the dry valley systems of the South Downs. Here numerous dry valleys heading behind, but not breaching, the main Chalk escarpment coalesce to pass through three gaps in the secondary escarpment, and again coalesce to pass out to the Coastal Plain by the single outlet at Clapham. The secondary escarpment here consists of the separated hills of Wepham Down, Harrow Hill, Blackpatch Hill and Church Hill; Topley described it as the remains of an old escarpment [5], but Mr. Osborne White regards the discontinuity of the secondary escarpment as a sign of immaturity rather than decadence [6, footnote on page 7]. It seems clear that the development of this valley system must have been initiated before the development of the secondary escarpment, and since the dry valleys do not breach the main escarpment, their development was presumably subsequent to the time when the main escarpment reached its present position.

The next halt was made near the top of Church Hill, on the east side of which, overlooking the Findon Valley, is a group of Neolithic or Early Bronze Age Flint Mines, which were dug in the zone of *Actinocamax quadratus*. One of these mines had been recently opened up by Mr. J. H. Pull, who met the party on the site and showed them the mine, which consists of a wide shaft about 15 feet deep, with several short galleries radiating from the bottom. Mr. Pull described the geology of the site and exhibited a number of fossils which had been collected during the excavations and determined by Mr. C. P. Chatwin; among them were *Actinocamax quadratus*, which is a very rare fossil in Sussex, and *Belemnitella mucronata*, which has not previously been recorded from the Sussex Downs, although it occurs, in its own zone, on the foreshore at Felpham and Dell Quay, in the west of the county, and has been recorded from the *quadratus* zone in Hampshire.

After the President, Mr. E. E. S. Brown, had moved votes of thanks to the Director and Mr. Pull, the party descended into the Findon Valley, which differs from the dry valleys seen earlier in the afternoon in that it leads to a marked wind-gap in the main Chalk escarpment, with the Downs rising between 300 and 400 feet above it on either side. This valley may therefore be assumed to be a relic of the drainage of Pliocene or earlier times, when the escarpment extended much farther to the north. Tea was taken at the Old Village Guest House, Findon.

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THE ORIGIN OF CERTAIN ROCK STRUCTURES NEAR ABERYSTWYTH

By JOHN CHALLINOR

[Received 21st January, 1948]

IT has always been assumed that the various folds and faults in the Aberystwyth strata, of Upper Valentian age, have been produced by crustal stresses after the Silurian rocks as a whole had been deposited and more or less completely consolidated. The observation of certain facts, however, together with a consideration of first principles, suggests that this general assumption has been too readily taken for granted. Probably most of the structures are of this subsequent (secondary) origin, but others, showing special features, may have been produced during the consolidation of the deposits.

It seems possible that there are various kinds of primary deformation, linked in time, leading into that kind of deformation which is completely tectonic, or secondary. There may not be such a great hiatus between "contemporary" and "subsequent" deformation as is usually supposed.

Three main types of primary deformation may perhaps be recognised:—

1. Individual beds, a few inches to a few feet in thickness, usually with some of the features of "graded bedding," showing internal folding and crumpling. The pale siltstone bands (the "grits") of the Aberystwyth formation show excellently this type of deformation, but they are not further considered here. This small-scale type of deformation is referred to by Bailey (1930, p. 85)* and also by Jones (1938, p. lxiv), who implies the existence of the two types, 1 and 2 of the present paper. Examples from Scotland are described by Henderson (1935) and one from the Lake District by Hartley (1932, p. 56). The undulations and contortions seem likely to have been produced during the actual process of deposition of the silt with very little, if any, translatory movement of the "bed" as a whole.

2. Beds, often some 10 to 100 feet thick, showing internal contortions produced by "slumping." This phenomenon has lately become familiar through several published accounts, and the process has been fully discussed by Jones (particularly 1939a, p. 369; see also 1939b and 1944). Some of the most thoroughly investigated examples are those in the Wenlock and Ludlow rocks of Wales (Jones, 1937, 1939a, 1947 and Earp, 1938). Beets (1946) gives many references, but none to Wales.



A.—Asymmetrical fold dying out upwards.



B.—“Clot” of disturbed beds.

LOCALISED STRUCTURES IN THE ABERYSTWYTH GRITS, CLARACH BAY,
CARDIGANSHIRE.

Each view, A and B, shows the rocks to about the same scale, the several thickest grit bands seen being about eight inches thick.

[To face p. 48.

3. Strata deformed by movement under gravity within a partly consolidated mass of sediments. It is to this category that, it is suggested, some of the minor folds and other deformations in the Aberystwyth rocks may belong. That such movement is likely to occur and produce comparatively large and regular structures is implied in several published diagrams, such as those by Twenhofel (1939, Fig. 39) and Grabau (1932, Fig. 131, after Heim), and Brown (1938, p. 361) recognises zones of different kinds of flow in beds in various stages of consolidation. Grabau (1932, pp. 660, 780) remarks that the structural forms thus produced might resemble truly tectonic structures. Deformation of this origin would be called penecontemporaneous by Jones in contrast to the strictly contemporaneous origin of types 1 and 2 (see Jones, 1943, p. 67). The examples of deformation described by Baldry (1938) and Dunnington (1944, p. 245 and Fig. 3) seem to belong to this third type.

Although there is a clear distinction, as regards origin, between deformation due to slipping under gravity and that due to lateral earth-pressure, the one process may grade into the other, as regards time. As contemporary, and penecontemporary, deformation is visualised as continuing during the compaction and consolidation of the sedimentary series (becoming less and less "contemporary"), so the earth-pressures due to the development and contraction of a geosyncline may well have their first beginnings while movement under gravity is still a possibility. The degree of consolidation of beds when they suffered tectonic deformation is an important question that is usually given little attention when the geological history of a formation is being considered; but it is likely that, in many cases, folding by lateral pressure began to be imposed on rocks when their consolidation was by no means complete. Nor is it an impossibility that a particular deformation, or set of deformations, should be produced partly by slipping under gravity and partly by lateral earth-pressure; that is, by the combination of two distinct processes.

Some examples of movement and deformation which can be proved to be of secondary, tectonic origin have been described; probably the most complete demonstration being that given by Cope from the Millstone Grit (1945). In the Aberystwyth rocks themselves, certain small-scale corrugations have recently been cited by Lewis (1946) as evidence of a rucking effect of movement between bedding planes. There are cases where intraformational folded, contorted and broken beds have been described and accounted for by a purely tectonic process, such as drag-folding, where nevertheless the possibility of a contemporaneous origin is perhaps not completely ruled out (e.g., Arkell, 1938), while others originally ascribed to tectonics are now accepted as primary (e.g. Miller, 1908).

The "curious marks" described by the present writer some

time ago (1926 and 1929) as occurring in the Aberystwyth rocks on bedding surfaces which had been smoothed, polished and striated, evidently as the result of movement, are also of interest in connection with the present inquiry. There are two specially peculiar features about these marks :—(1) that the shape of the individual marks varies greatly over an area of a few square yards, and (2) that fossils (graptolites and, in one instance, a brachiopod, not flattened) show no sign of having been scraped along the surface. The fossils indeed seem less rare on these surfaces than on others. It may also be mentioned that at the well-known locality for certain species of *Monograptus*, Cefn Hendre quarry on the hill above the town, the graptolites are to be found chiefly on bedding surfaces which have a polished appearance. One would have expected any fossils to have been ground up, broken or, at least, distorted on any surface that had acquired a slickenside effect. Could the marks have been produced by a slithering between bedding surfaces when the rocks were still very plastic?

Two examples of the kinds of structure here in question are shown in the photographs forming Plate 1. They occur, about 100 yards apart, in the cliffs to the north of Clarach Bay. It will be seen that the asymmetrical fold (Fig. A) suddenly dies out upwards, while the other example (Fig. B) is a "clot" of disturbed, broken and folded beds. It is difficult to prove whether these structures are penecontemporaneous or not, as the characteristics of slumped beds, and also the characteristics of the type of secondary deformation described by Cope, are naturally both absent. But it is the extreme localisation of such structures that seems so much easier to account for on the hypothesis here put forward than as a response, by a thick, and already consolidated, formation, to a purely subsequent tectonic pressure. As already suggested, deduction from first principles leads one to expect, or at least to look for, structures produced in this way.

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DISCUSSION

MR. G. THEOKRITOFF stated that if it be accepted that the Aberystwyth Grits had been deposited in a part of the geosyncline where the sea-floor had an approximately uniform slope towards a given direction, then it is reasonable to expect that any gravity-initiated structures would show a common orientation controlled by the tendency towards gravitational movement in the direction of maximum slope. He asked whether it were possible to determine the direction of any movement there may have been in connection with the formation of these structures. If so, he suggested that it might be possible to throw additional light on the origin of these structures by a comparison of the direction of each movement with the tectonic pattern of the area concerned.

PROFESSOR T. NEVILLE GEORGE said that very similar structures to those seen in the Aberystwyth Grits were to be observed in other sediments in Wales : he instanced certain limestone-shale facies in the Carboniferous Limestone, sandstone-shale facies in the Millstone Grit, and the Blue Lias. In all of these the structures, sometimes as small faults, sometimes as puckerings and small folds, appeared to be strictly tectonic in origin, and never to be the result of penecontemporaneous movement under gravity of "plastic" unconsolidated sediments.

In the Carboniferous strata true slumping was shown by autobrecciation and by welding at the junction of the overlying undisturbed post-slump beds with the beds beneath. The minor fractures and folds, on the other hand, though often ending abruptly (both upwards and downwards) against an apparently undisturbed layer, were proved to be tectonic by the occurrence of slickensides on the surface of junction. The "subsequent" nodular limestones of the Blue Lias (as for instance in Dunraven Bay) were manifestly brittle ribs at the moment of deformation—or at least were not plastic in the everyday meaning of that term.

It was occasionally possible to relate the highly localised minor structures to major folds or faults of tectonic origin long subsequent to sedimentation. They then had all the aspect of drag structures typical of incompetent strata caught up by compensatory movements along flanking bedding planes.

He asked the Author if any indication of plastic deformation could be discerned within the puckered Aberystwyth Grits, or if conversely the base of the overlying undisturbed beds showed glissaded or striated surfaces.

DR. A. J. BULL said that he had been most interested in the minor folds described by Mr. Challinor. They were certainly not produced by slumping, if slumping might be defined as the movement under gravity of sediments in contact with water, because nothing had been removed from the upper part of either fold, and there was no sign of a local deposit from the cloud of sediment that would go up into the water from the surface movement. The structures were evidently due to relative movement between the beds above and below, probably the beds above had moved over the lower ones under the force of gravity.

Dr. Bull agreed with Mr. Challinor's suggestion that the deformation might have taken place at an early stage in the consolidation of the rocks.

P. G. H. BOSWELL sent the following written contribution :

Mr. Challinor has kindly allowed me to read the manuscript of his interesting paper, from which I am glad to find that our thoughts have been running on parallel lines. I suggest that lengthy experience of the "feel" and behaviour of unconsolidated sediments, and an appreciation of their relative strength—and weakness—convinces the observer that many of the disturbances they have suffered were imposed when they were neither loosely organised on the sea or lake floor, nor completely consolidated.

The nature of the folding and fracturing of many of the intra-formational occurrences of disturbed deposits indicates that they were in a plastic condition (in the everyday sense) when movement took place. The depth at which they lay below the sea floor is indeterminable in our present state of knowledge. To argue that the disturbance resulted from the sub-aqueous sliding of water-logged sediment, as though the latter could exercise a strong frictional drag on a considerable thickness of underlying deposits, is to my thinking to put the cart before the horse. Rather, it seems probable that small sub-aqueous slides were the superficial manifestation of the movement that produced the crumpling of plastic sediments in depth, movement which was thus not contemporaneous with deposition of the latter.

Sub-aqueous sliding on a large scale is hypothetical. One may reasonably ask where, at the present time (when gradients and denudation are believed to be greater than the average during geological history), such large-scale disturbance of thick bodies of sediment is observable. The examples of sub-aqueous sliding recorded in our time are those in certain Swiss lakes, in which cases the slipped material amounted to only a few metres in thickness, and was not observed to be crumpled. Moreover, it slid, not under its own weight purely, but because of overloading of the neighbouring shores : in short, the slipped masses were essentially landslides initiated by human action.

The literature of "slumped" deposits is now considerable. We should not forget that it represents the erection of a great pyramid of inference on an

apex of doubtful, or no, magnitude. The presence of an erosional plane above an intraformationally-crumpled bed, for example, is not necessarily evidence of contemporaneous disturbance.

Mr. Challinor's account of the various types of disturbance will be studied with interest and gratitude. Especially, we should be glad to know the criteria that lead him to infer the effects of movement under gravity of a partially consolidated mass, and those that suggest "slumping"—itself an ambiguous term that needs careful definition.

The Author, in a very brief reply to some of the points raised, thanked the members for the kind way in which they had received a paper on a somewhat speculative and controversial topic, and said he was particularly grateful for the valuable remarks made by those who had taken part in the discussion.

FIELD MEETING AT BOGNOR REGIS AND BRACKLESHAM BAY

22nd and 23rd May, 1948

Report by the Director : Edmond M. Venables, F.G.S.

[Received 23rd November, 1948]

SOME 20 members of the Association gathered at the Marine Parade Hotel, Bognor, headquarters of the meeting, in the evening of Friday, 21st May, and the Director gave a talk on the objects of the Excursion. Bognor and Bracklesham Bay, he said, were most difficult places in which to plan field meetings, because, in each case, the principal field of interest was the outcrop of the Eocene strata on the foreshore. This outcrop being only accessible at extreme low tide, it must be examined in the morning or evening, the time of low water during spring tides. It was, therefore, necessary to arrange a supporting programme for the middle of the day. The Director then explained the tectonic structure and stratigraphical features of the district, and illustrated the palaeontology by handing round a series of Eocene fossils collected locally.

The following morning, 22nd May, the party, swelled by the arrival of other members living near Bognor, left headquarters at 10 a.m. and travelled by public bus to Lavant. Alighting at Lavant station, the party walked through East Lavant, ascending the dip-slope of the Downs to the chalk pit beside the Chichester Corporation's Waterworks. Here the party divided, some remaining in the chalk pit and the remainder continuing the ascent of Trundle Hill, one of the highest points in West Sussex. From this vantage point the Director indicated the salient physiographical and topographical features of the wide view, and again explained the tectonic structure, pointing out the positions occupied by the various geological formations. The day was fine and warm, but a slight haze obscured the Isle of Wight from view. Returning to the chalk pit, the party reunited for a picnic lunch, after which some time was spent in collecting fossils, the chalk represented in the pit being in the sub-zone of *Offaster pilula*. A fine tooth of *Corax falcatus* was found by a member. The party then travelled by bus to Chichester and on to Selsey, where the Director led them to the beach and along the foreshore on the west side of Selsey Bill, north-west toward Bracklesham Village. En route, an exposure of Auversian clay, with fossils, was examined. The horizon of the exposure was difficult to determine, but it was probably just above the Medmerry Bed. In the hope of seeing the Brook Bed exposed, the party continued north-westward, but though the unfossiliferous grey clay immediately overlying the Brook Bed was exposed to view the latter was unluckily obscured by beach sand. Retracing their

steps, and collecting Eocene fossils cast up on the sands, the party found a small exposure of the Medmerry Bed just uncovered by the tide, and some members waded out to raised portions to collect therefrom. The party then returned to Bognor via Chichester by bus.

After dinner at the hotel, the Director introduced Miss A. D. French, J.P., who, though not a member, had kindly agreed to conduct part of the supporting programme. The Director said that Miss French was the leading expert on Pagham Harbour, to which place the party would pay a visit the following morning. Miss French then gave a short talk on the physiographical features of Pagham Harbour and the remarkable series of changes, within historic times, in the position of the harbour mouth and of the shingle banks, and the effect of these changes upon the plant-ecology of the area.

The following morning, Sunday, 23rd May, the party left headquarters at 10.30 a.m., travelling by bus to Pagham. Miss French conducted them round Pagham Lagoon and out to the new harbour mouth, artificially formed about 12 years ago. Prior to 1876 the mouth was much farther east than its present position, and the channel was flanked on its seaward side by a long and increasing shingle spit, a deflection feature also seen at other places on the south coast. In the year mentioned reclamation work involved a change in the position of the mouth, and the old channel, evacuated by the water, is still seen, as "Pagham Hollow," together with the still-existing shingle spit. In 1910 the sea broke through the shingle bank and reoccupied the old channel to a depth of four feet. Further work resulted in the reclamation of the old channel, and it was colonised in turn by a salt marsh flora and then a fresh-water flora, as the effect of fresh springs exerted itself.

After a picnic lunch by Pagham Lagoon, the party travelled by bus to Aldwick, where the Director led them down to the shore by Dark Lane to examine an artificial accumulation of boulders on the beach. This accumulation is situated near the point where the outcrop of the Bognor Rock runs inshore, and it is largely composed of Bognor Rock collected in the immediate vicinity; but amongst the boulders are many examples of the Barn Rock transported here from the outcrop of that horizon much farther west. The Director drew attention to the difference in lithological character between the Bognor and Barn Rock types, the former being a grey arenaceous limestone and the latter a green glauconitic sandstone. He also emphasised the fact that, contrary to a general belief, the Bognor Rock is only fossiliferous in patches, the crowded masses of fossils in the rock seen in collections and museums giving a wrong impression. The Bognor Rocks are of concretionary origin, and occur through the induration of the sand in a sandy layer in the London Clay. The erosion of the unconsolidated sand in which the

concretions formed leaves the latter as the well-known reef of large rocks, a most impressive feature, at low tide, of local coastal scenery. Mr. A. Wrigley impressed upon those present the massive nature of these concretions, stressing the fact that as such they are without parallel in British Eocene geology.

The party then walked eastward along the shore, in drizzling rain, in the hope of seeing an exposure of some of the lower horizons of the London Clay, but the strength of the wind prevented the tide from receding far enough to expose any more than limited areas of the *Astarte* and Starfish Beds, where, however, some typical fossils were collected. This concluded the field meeting, and Mr. Wrigley, representing the President, called for a vote of thanks to the Director and Miss French, remarking that the party had seen more of the London Clay of the district than might have been expected, for he fully appreciated the difficulties experienced in such a foreshore area as this. He thought the Director had done well in planning and carrying out a field meeting here with such success.

FIELD MEETING AT ROTHAMSTED EXPERIMENTAL STATION, HARPENDEN

Saturday, 1st May, 1948

Report by J. F. Kirkaldy, D.Sc., F.G.S.

[Received 18th October, 1948]

THIRTY-EIGHT members and friends assembled at 2.30 p.m., and were conducted in three parties round the newly-established Pedological Department. The demonstrations consisted of the use of X-ray diffraction technique in the study of clay minerals, of spectrographic analysis in the investigation of trace element deficiencies and a study of the weathering of the rocks of the Malvern Hills.

After tea had been served in the Social Centre, the Director, Dr. W. G. Ogg, welcomed the party, and the President, Mr. E. E. S., Brown, in his reply, voiced the thanks of the party to Dr. Ogg and to Dr. A. Muir, head of the Pedological Department, and his staff for the very instructive demonstrations.

The party then divided into two groups and were conducted round the farm. This gave an opportunity for studying the effectiveness of different amounts and types of fertilisers and of comparing the classical and the modern layout of experimental fields. Broad-balk with its long strips showing the older method and a field with small randomised blocks the latest method. The party dispersed at about 6 p.m.

DEMONSTRATION AT THE INSTITUTE OF ARCHAEOLOGY

Saturday, 9th October, 1948

Report by J. F. Kirkaldy, D.Sc., F.G.S.

[Received 9th October, 1948]

ABOUT 100 members of the Association, the Prehistoric Society of East Anglia and the Richmond Natural History Society assembled at 3 p.m., and were welcomed by Prof. V. G. Childe, Director of the Institute. Prof. F. E. Zeuner then briefly outlined the main features of the exhibits, which included recent and fossil soils, numerous implements, arranged mainly to show typology, from many localities in Africa and Europe and reconstructions, several in the form of dioramas, of Pleistocene mammalia. Full details of the demonstration, together with references, are to be found in "The Exhibition of Stone Age and Pleistocene Geology from the Cape to Britain," Occasional Paper No. 9 of the Institute. This demonstration had been specially prepared for the 18th International Geological Congress. Whilst members were examining the exhibits, Mr. I. W. Cornwall, B.A., demonstrated M. Léon Coutier's technique for making flint implements.

THE ANNUAL REPORT OF THE COUNCIL OF THE GEOLOGISTS' ASSOCIATION FOR THE YEAR 1948

[Adopted at the Annual General Meeting on March 4th, 1949.]

THE numerical strength of the Association on December 31st, 1948, was as follows :—

Honorary Members	18
Ordinary Members :— ..	
Life Members (compounded)	161
Annual Subscribers	1510
	1689

During the year 257 new members (a record number) were elected, and the Association lost 52 members through death, resignation and removals under Rule XI for failure to pay subscriptions. The membership continues to rise, and shows an increase of 205 over that of the previous year.

The list of deceased members is as follows :—Mrs. H. H. Bemrose, A. K. Coomaraswamy, C. C. Duncan, A. S. Kennard, H. J. Kinghorn, H. W. Lewin, S. L. Lightfoot, Miss S. MacCarthy Morrogh, E. J. Pegg, J. Pringle, R. L. Sherlock, E. W. Tunbridge and A. J. Wigmore.

Obituary notices will be found on pages 78–86.

FINANCE

On the Income side of the General Purposes Account, the income from admission fees and annual subscriptions has achieved a new record at £826 as compared with £712 in 1947, £642 10s. in 1946, and £601 in 1945. On the Expenditure side of the Account, it should be noted that the cost of the *Proceedings* includes five Parts instead of the usual four. Since 1942, Part 4 of the current volume has always been issued too late to be included in the Accounts for the year ; in 1947 both Part 3 and Part 4 of Vol. 58 were issued too late for inclusion. To meet the cost of these Parts, it has been necessary to transfer the sum of £400 from the Special Funds to the General Purposes Account. After providing for the transfer, the balances in the various Special Funds, apart from the Reserve Fund for Index and List of Members, amount to £299 15s. 9d. This sum is available for the general purposes of the Association, and is in addition to accumulated funds of £124 1s. 10d. Since the

closing of the accounts for the year, a grant of £200 has been received from the Royal Society towards the cost of publishing certain papers. The financial position of the Association may therefore be regarded as satisfactory, although the heavy increases in almost all items of expenditure, particularly in the cost of publication, must still give rise to some anxiety for the future.

Illustrations Fund

Contributions to the Fund amounted to £99 3s. 4d. from 123 members. This is an improvement on last year, when £64 1s. was contributed by 97 members, but the proportion of members supporting the fund is only seven per cent of the membership. In view of the high cost of illustrations at the present time, increased support for the Fund is very much to be desired.

Foulerton Award Fund

An award of £10 has been made from the Foulerton Award Fund, and the balance remaining in the Fund at the end of the year was £18 13s. 3d.

Under the Transport Act, 1947, £255 Southern Railway five per cent Guaranteed Preference Stock standing to the credit of this fund was converted into £349 7s. British Transport three per cent Guaranteed stock 1978/88, thereby reducing the Annual income from £12 15s. to £10 9s. 8d.

ACCOUNTS FOR THE YEAR ENDING DECEMBER 31st, 1948

GENERAL PURPOSES ACCOUNT.

INCOME		£	s.	d.	£	s.	d.	EXPENDITURE
To Admission Fees :—								By "Proceedings" of the Association (Vol. 58, Parts 3 and 4, and Vol. 59, Parts 1, 2 and 3) :—
Received for 1948 Elections	...	103	0	0	...	705	13	(1) Printing
Received for Arrears	...	12	10	0	...	232	17	(2) Illustrations
					...	40	15	(3) Authors' separate copies
Less Arrears at December 31st, 1947, £14 10s., estimated to realise	...	115	10	0				
								Printing Monthly Circulars
Add Arrears at December 31st, 1948, £24, estimated to realise	...	12	0	0				Stationery
								Expenses at Meetings
								Addressing and Stock-keeping
								Postages
								Insurance
								Incidental Expenses
								Yearly transfer to Reserve Fund for Index and List of Members
								Map-mounting and Book-binding
To Annual Subscriptions :—								
(1) Received in 1944, 1945 and 1946 for 1948	...	3	0	0				
(2) Received in 1947 for 1948	...	68	0	0				
(3) Received in 1948 for 1948	...	577	0	0				
(4) Received in 1948 for arrears	...	44	10	0				
Less Arrears at December 31st, 1947, £71, estimated to realise	...	692	10	0				
Add Arrears at December 31st, 1948, £87, estimated to realise	...	662	10	0				
To Royal Society Grant	...	40	0	0				
" Sale of Publications	...							
" Miscellaneous receipts	...							
" Transfer from other Accounts :—	...							
From Illustrations Fund Account (for Illustrations)	...	100	0	0				
" Compounding Fund	...	250	0	0				
" Bequest Funds...	...	50	0	0				
" Excess of Expenditure over Income for the year	...							

BALANCE SHEET, DECEMBER 31st, 1948.

[illegible]

SPECIAL ACCOUNTS ILLUSTRATIONS FUND

	£	s.	d.		£	s.	d.
To Balance in hand on January 1st, 1948	...	22	19	1	...	100	0
Donations and Subscriptions	...	99	3	4	...	0	0
Transfer from Illustrations Fund (Capital)	...	...	12	6	...	22	14
						11	11
					£122	14	11

SPECIAL ACCOUNTS (*continued*) ILLUSTRATIONS FUND (CAPITAL)

To Balance in hand on January 1st, 1948	£ s. d.				£ s. d.
„ Dividends as received :—	...	...	...	By Transfer to Illustrations Fund	...
£21 0 10 Metropolitan Water Board 3% B Stock	...	...	12 6	„ Balance December 31st, 1948	...
			<u>£0 12 6</u>		<u>£0 12 6</u>

COMPOUNDING FUND.

To Balance in hand on January 1st, 1948	£ s. d.				£ s. d.
„ Composition Fees received during the year	...	...	123 18 2	By Transfer to General Purposes Account	...
„ Dividends as received :—	...	...	232 7 4	„ Balance December 31st, 1948, at Bankers	...
£1,217 2 6 Nottingham Corporation 3% Stock	36 10 2				...
£170 0 0 3½% War Stock	5 19 0				...
£300 0 0 3% Savings Bonds	9 0 0				...
			<u>51 9 2</u>		<u>£407 14 8</u>

RESERVE FUND FOR INDEX AND LIST OF MEMBERS.

To Balance in hand on January 1st, 1948	£ s. d.				£ s. d.
„ Yearly Reservation for 1948	...	...	76 0 0	By Balance December 31st, 1948, at Bankers...	...
	...	...	40 0 0		...
			<u>£116 0 0</u>		<u>£116 0 0</u>

BEQUEST FUNDS.

To Balance in hand on January 1st, 1948	£ s. d.				£ s. d.
„ Dividends as received :—	...	...	147 9 8	By Transfer to General Purposes Account	...
£143 8 9 3½% War Stock	5 0 6			„ Balance December 31st, 1948, at Bankers	...
£150 0 0 New Zealand 3½% Stock	5 5 0				...
£285 0 0 3% Defence Bonds	8 11 0				...
£100 0 0 3% Savings Bonds, 1960/70	3 0 0				...
			<u>21 16 6</u>		<u>£169 6 2</u>

“TRUST” FUNDS

FOULERTON AWARD FUND.

To Balance in hand on January 1st, 1948	£	s.	d.				£	s.	d.
„ Dividends as received :	...	...	...	...	...	...	...	...	...
£255 0 0 Southern Railway 5% Guaranteed Preference Stock	3	10	2				...	...	...
£349 7 0 British Transport 3% Guaranteed Stock	2	17	8				...	...	...
„ Income Tax repayment for 1947/48...	2	17	5				...	...	...
	£28	13	3						

By Award to Miss E. White, B.Sc., F.R.G.S.
 „ Balance 31st December, 1948, at Bankers

G. W. YOUNG GEOLOGICAL INVESTIGATION FUND.

To Balance in hand on January 1st, 1948	£	s.	d.				£	s.	d.
„ Income for 1947 and 1948, received from the Public Trustee	...	...	...	...	...	...	...	...	...
„ Income Tax repayment	...	...	...	...	...	...	...	...	...
	£89	13	4						

By Income Tax repayment paid to Public Trustee
 „ Balance 31st December, 1948, at Bankers

HENRY STOPES MEMORIAL FUND.

To Balance in hand on January 1st, 1948	£	s.	d.				£	s.	d.
„ Dividends as received :	...	...	...	...	...	...	...	...	...
£265 19 2 Government of Newfoundland 3% Stock, 1943/63	4	7	10				...	...	...
„ Income Tax repayment for 1947/48	3	11	8				...	...	...
	£14	3	2						

By Balance 31st December, 1948, at Bankers...

We have compared these statements with the books and accounts presented to us and find them to agree.

We have also verified the investments of £1,217 2 6 Nottingham Corporation Stock, £200 3% Savings Bonds, 1955/65 £100 3% Savings Bonds, 1965/75, and, £170 3½% War Stock of the Compounding Fund, £349 7 0 British Transport 3% Guaranteed Stock, 1978/88, of the Foulerton Award Fund, £143 8 9 3½% War Stock, £150 New Zealand 3½% Stock, 1960/64, £285 3% Defence Bonds and £100 3% Savings Bonds, 1960/70, of the Bequest Funds; £21 0 10 Metropolitan Water Board 3% B Stock of the Illustrations Fund (Capital), and £265 19 2 Government of Newfoundland 3% Stock, 1943/63, of the Henry Stopes Memorial Fund.

W. DACK, *Treasurer.*

29th January, 1949.

T. BARNARD
 H. PICKWORTH

} *Auditors.*

PUBLICATIONS

Publications Committee.—The Committee consisted of the officers (seven), together with Mr. C. E. N. Bromehead, Dr. S. Buchan, Mr. T. Eastwood, Dr. J. F. Kirkaldy, Mr. G. S. Sweeting and Mr. A. Wrigley. The Committee met on five occasions, and considered 22 papers, reports regarding these were made to the Council.

The Proceedings.—It was not possible to issue all four parts within the year, but it is now expected to issue future parts to time. The Proceedings contained 276 pages and was well illustrated.

MEETINGS

Nine Ordinary meetings were held, at which five papers were read and four lectures were given.

The thanks of the Association are due to the Authors and Lecturers. The average attendance at meetings, 81, was slightly below that of last year.

The meetings were held at the apartments of the Geological Society of London, and the Committee Meetings at the Imperial College of Science and Technology (Royal School of Mines).

The Association's thanks are due to the respective authorities for the facilities afforded.

REUNION

The Annual Reunion was held at the Chelsea Polytechnic on Saturday, 6th November. A number of interesting exhibits were shown, and the attendance exceeded that of last year. Thanks are due to the authorities of the Chelsea Polytechnic, the organisers and the members concerned.

A full account of this meeting will be given in the Report of the Session.

FIELD MEETINGS

The Committee consisted of the officers (seven), together with Messrs. F. H. Edmunds, C. T. A. Gaster, J. F. Kirkaldy, C. D. Ovey, H. W. Pickworth, W. S. Pitcher, J. D. Weaver and M. K. Wells. After the termination of the International Geological Congress, Dr. J. F. Kirkaldy took over the duties of Secretary from Dr. G. W. Himus.

The Association took an active part in arranging and providing Directors and Leaders for the day and half-day Excursions of the 18th International Geological Congress. In all, 95 excursions were arranged, and although only 65 took place, great satisfaction was expressed by the participants.

The heavy calls made by the Congress on the services of Directors made it impossible to organise Field Meetings after July, consequently the usual long summer meeting could not be arranged. In all, 21 Field Meetings were held, consisting of 11 half-day, eight whole-day, and two weekend. The average attendance was 30.

The best thanks of the Association are due to the Directors and others who organised and assisted at the meetings.

It is satisfactory to record that although a number of our older and well-tried Directors are no longer available, they are steadily being replaced by a new generation of young and enthusiastic Directors and Secretaries who are worthily maintaining the standard of our Field Meetings.

THE LIBRARY

The Library Committee consisted of the Officers together with Dr. S. Buchan, Dr. L. J. Chubb, Messrs. R. V. Melville, G. S. Sweeting, and the University College Librarian. Arrangements for the exchange of publications have been made with a number of overseas institutions not previously on the exchange list. Thanks are due to the donors of a number of books, maps and pamphlets, listed in the *Proceedings*.

GEOLOGY IN SCHOOLS

The Association's symposium on "The Teaching of Geology in Schools" has been widely publicised and the numbers of copies distributed are as follows :—Thirty to members of the Inspectorate of the Ministry of Education, 83 to Public Schools (boys), 76 to Education Departments of Universities, University Colleges and Teachers Training Colleges, and smaller numbers have gone to other schools, societies, museums, associations, county education departments and individuals.

It is interesting to note that some schools are now including geology in their courses for the first time.

WEALD RESEARCH COMMITTEE

Two papers were published in the *Proceedings*. They are the Committee Reports Nos. 39 and 40 on Clock House Weald Clay pit and on Tilburstow Hill. Field meetings were conducted in the N.W. Weald and at Tilburstow Hill, and members of the Committee were also responsible for various excursions of the International Congress and of the British Association meeting at Brighton.

NORTH-EAST LANCASHIRE GROUP

Chairman : J. Ranson, A.M.I.M.E., F.G.S.

Joint Secretaries : Mrs. Harrop, B.A., B.Sc., D. H. Learoyd, B.Sc., F.G.S.

During the year four lectures were given and four field meetings were held. Particulars will be published in the Report of the Session.

In November the Group celebrated its twenty-fifth anniversary.

MIDLAND GROUP

Chairman : A. L. Lyon, M.Inst., C.E., M.Inst, W.E., F.G.S.

Secretary and Treasurer : Miss Grace M. Bauer.

Committee : Professor L. J. Wills, Messrs. A. J. Aiers, W. G. Hardie, H. M. Sale, F. Smith.

During the year five Lecture Meetings were held at the Geological Department, the University, Birmingham, and there were three Field Meetings. Particulars will be published in the Report of the Session. The average attendance was 42.

Thanks are due to Professor Wills for the use of the Geological Department at the University for meetings.

TRUSTEES

The Trustees of the Association are :—

Managing : Mr. F. N. Ashcroft, M.A., F.G.S., F.C.S., F.R.G.S.
Mr. S. Hazzeldine Warren, F.G.S., and Dr. W. F. Fleet, M.Sc.
A.R.I.C., A.C.P., F.G.S.

Custodian : The Royal Bank of Scotland, Western Branch.

FOULERTON AWARD

The Foulerton Award for the year was given to Miss Elsie White, B.Sc., F.R.G.S., for services rendered to the Association.

HOUSE LIST

Mr. Eastwood and Mr. Bromehead retire as vice-presidents and Dr. Chubb, Mr. Gaster, and Mr. Kellaway as Ordinary Members of Council. Thanks are due to these members for services rendered to the Association.

During the year Dr. Himus retired from the office of Field Meetings Secretary and special thanks are due to him for his services during a most difficult period.

REPORT OF THE SESSION, 1948

Ordinary Meeting, 2nd January, 1948.—Mr. C. E. N. Bromehead, B.A., F.G.S., President, in the chair.

Mrs. Basil Ainsley, Richard Wallis Andrews, David Atkin, Robert Geoffrey Atkinson, Frederick James Fitzmaurice Barrington, Terence Stanley Busby, Raymond Charles Carter, Walter Dinwoodie, A.R.S.M., M.I.M.M., John Thomas Dodd, Wilfred Thomas Edwards, Cyril Ernest Everard, Norman Leslie Falcon, John Derrick Godfrey, Henry Eric Hardy, Brian William Hester, Ronald Herman Charles Holman, Miss Hilda M. Hutchins, Philip Frank Hutchins, Basil Isaac, Leonard Knowles, Derek Hudson Learoyd, B.Sc., F.G.S., Charles Henry Lock, Peter Inglett Manning, Frank Alexander Middlemiss, Margaret Olwen Morris, Edward Ambrose Oliver, William Alfred Read, Herbert Esmond Robins, Nathaniel Rothenburg, John Blomerley Scholefield, M.I.Struct.E., M.I.Q., Miss Daphne Sidebottom, Arthur Michael Marshall Spurr, Dr. Charles Hugh Christie Toussaint, M.R.C.S., L.R.C.P., D.P.H., Ralph Hubert Ritchly Vine, and Gilbert Harry Whiting were elected Members of the Association.

Messrs. J. D. Weaver and T. Barnard were elected auditors of the accounts for 1947.

The following paper was read :—" Underground Water Supplies for War Purposes in England and Wales, 1939-45," by F. H. Edmunds, M.A., F.G.S.

Ordinary Meeting, 5th February, 1948.—Mr. C. E. N. Bromehead, B.A., F.G.S., President, in the chair.

Miles L. Ainsworth, Audrey Ellen Ashworth, John Maurice Branson, Ronald Stanley Brewis, David James Carter, B.Sc., A.R.C.S., F.G.S., Richard John Chorley, Alice Mary Coleman, B.A., Reginald Thomas Cornish, B.Sc., A.K.C., Trevor David Ford, V. Gilberthorpe, John Adolph Haas, B.Sc., William Edwin Haigh, F.R.C.S., D.P.H., Peter Henry John Hammett, Professor Ph. H. Kuenen, Robert Edward Hay Reid, (Syed) Usman Ali Shah, Edward Arnold Shaw, Bruce Wilfred Sparks, B.A., Walter Edward Tremlett, Peter Lloyd Walker, Michael Wyatt, and Harry Raymond Murray Young were elected Members of the Association.

The following lecture was delivered :—" A Year in Graham Land," by W. N. Croft, B.A., F.G.S.

Annual General Meeting, 5th March, 1948.—Mr. C. E. N. Bromehead, B.A., F.G.S., President, in the chair.

The Annual Report of the Council (already circulated) was taken as read. It was moved by Mr. Higginbottom and seconded by Mr. G. Thomas, " That the Report of the Council, including the Statement of Accounts, be adopted as the Annual Report of the Association for 1947." The resolution was carried *nem. con.*

The President declared the following members duly elected as Officers and Members of the Council in accordance with Rule XIII: President, E. Ernest S. Brown, M.B.E., F.G.S.; Vice-Presidents, T. Eastwood, A.R.C.S., F.G.S., G. S. Sweeting, D.I.C., F.G.S., C. E. N. Bromehead, B.A., F.G.S., E. C. Martin, O.B.E., B.Sc., A.R.I.C., F.G.S., A. Wrigley; Treasurer, W. Dack, I.S.O., F.G.S. Secretaries, General—R. Reeley, F.G.S., Field Meetings—G. W. Himus, Ph.D., M.I.Chem.E., F.G.S., Publications Committee—A. J. Bull, Ph.D., M.Sc., F.G.S.; Editor, K. S. Sandford, M.A., D.Sc., D.Phil., F.G.S.; Librarian, L. R. Cox, M.A., Sc.D., F.G.S.; twelve other Members of the Council, Miss M. A. Arber, M.A., F.G.S., F.R.G.S., S. Buchan, B.Sc., Ph.D., F.G.S., L. J. Chubb, Ph.D., M.Sc., F.G.S., C. T. A. Gaster, F.G.S., G. A. Kellaway, B.Sc., F.G.S., J. F. Kirkaldy, D.Sc., F.G.S., F. W. H. Migeod, F.R.G.S., F.R.A.I., Miss Mabel Tomlinson, B.A., D.Sc., Ph.D., F.G.S., J. D. Weaver, D. Williams, M.Sc., Ph.D., B.E., F.G.S., Vernon Wilson, B.Sc., Ph.D., D.I.C., F.G.S., C. W. Wright, F.G.S.

It was moved by Mr. D. R. A. Ponsford, seconded by Mrs. H. Himus, and duly carried "That the best thanks of the Association be given to the retiring President, the Officers, retiring members of the Council and the Auditors."

The Foulerton Award was presented to Miss Elsie White, B.Sc., F.R.G.S., in recognition of services rendered to the Association.

The President said:—

Miss White, the Council have this year selected you to be the recipient of the Foulerton Award, which is given for work of merit connected with the Association.

From 1937 to 1944 you served as secretary for Field Meetings, the post first occupied by Dr. Foulerton himself. In that way you have deserved well of our Association. But those of us who have the pleasure of knowing you personally are aware that you have, in addition, deserved well of our science. Though you may not have had the opportunity to deepen our knowledge of geology, you have done much to widen the interest in and the love of our subject amongst your pupils.

It is my privilege to hand you, in the name of the Geologists' Association, this token of our regard.

The President then delivered his address entitled "Practical Geology in Ancient Britain, Part 2, The Non-metals."

It was moved by Dr. H. Dighton Thomas, seconded by Mr. C. H. Dinham, and duly carried "That the best thanks of the Association be accorded the President for his Address."

Ordinary Meeting, 5th March, 1948.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Douglas Antony Bassett, Philip Claud Betambeau, Harry Leslie Boorer, Donald Ralph Bowes, Eric Herbert Brown, B.Sc., Owen Patrick Casey, Thomas William Dexter, Eric Arthur Edmonds, Norman Eric England, F.R.I.C.S., David Wallace Gossage, Chester

Gordon Guttridge, Willie Mawdsley, William Anderson Mitchell, Alexander Muir, Geoffrey Alan Peet, Phillip Edward Price, John Reekie, M.A. (Cantab.), and Patricia Jane Wortley were elected Members of the Association.

The following paper was "taken as read" :—" 'Sphaerocodium' : A mis-interpreted fossil from the Wenlock Limestone," by Professor Alan Wood, B.Sc., Ph.D., F.G.S.

Ordinary Meeting, 2nd April, 1948.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Alan Arthur Archer, Timothy Bagenal, Alfred Hugh Blissett, Robert Napier Clive Bowen, Alastair R. F. Buist, Elizabeth Mary Bulmer, Vincent Zachary Cope, Roy Albert Crowson, B.Sc., D.I.C., F.R.E.S., Frank Charles Dilley, Robert John Jones, William Stuart McKerrow, B.Sc., F.G.S., Robert William Marston, Kathleen Minikin, Peter Arkle Noyle, Claud Norris Rands, Geoffrey Victor Sandilands, Ian Patrick Stevenson, David Thatcher, Bertha Turner, M.D., and Gerald Edward Wilford were elected Members of the Association.

The following lecture was delivered :—" The Swiss Field Meeting, 1947," a description of slides and photographs by A. J. Bull, Ph.D., M.Sc., F.G.S., and P. E. Kent, B.Sc., Ph.D., F.G.S.

Ordinary Meeting, 7th May, 1948.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Reginald Bradshaw, Brian Sawyer Cron, Gordon Dilley, Anthony Farrington, D.Sc., Colin William Montgomery, Theodore Naish, and John David Slade were elected Members of the Association.

The following paper was read :—" Permo-Triassic Geology of South Cumberland and Furness," by K. C. Dunham, D.Sc., S.D., F.G.S., and W. C. C. Rose, M.Sc., F.G.S.

Ordinary Meeting, 4th June, 1948.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Gordon Robey Beckerleg, Peter Bentley, Alfred Norman Burton, Ralph Leslie Cheesman, Malcolm Geoffrey Clydesdale, Basil Elmsley Coke, James A. Dean, John Clifford Firman, Derek Flinn, Ronald E. G. Gregory, James Hargreaves, Frank Hay, Norman James Horrell, Anthony Vernon James, Donald Magraw, Frank Moseley, Edmund Neil Robertson, Gustav Anthony Schnellmann, A.R.S.M., B.Sc., Puthenveetil Abraham Varughese, and Godfrey Frederick Guy Worraker were elected Members of the Association.

The following lecture was given :—" A Cave Near Aberdare, Glamorgan : Geological Notes and Queries," by F. J. North, D.Sc., F.G.S.

Ordinary Meeting, 2nd July, 1948.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Yvonne Marguerite de Backer, Anthony Rene Barringer, Douglas William Clarke, Robert Bernard Doubleday, Brien Kenneth Drew, John Richard Duncanson, Archibald Eastmond, Florence Agnes Findlay, Kathleen Fitzpatrick, Derrick Arthur Freshwater, Oscar Rees Gibbon, Charles Alastair MacGregor Gray, Douglas Anthony Halesworth, Jessie Hall, B.Sc., Edith Margaret Headland, John Dennis Long, Ernest Eric Morgan, A.M.I.C.E., William Charles Pain, Norman John Payne, Peter Edward Price, Arthur Henry Ridout, Ursula M. Stephenson, B.Sc., and Geoffrey Arnold Wood were elected Members of the Association.

The following lecture was given :—"Early British Mineral Collectors and Mineral Collecting," by Sir Arthur Russell, Bart., M.B.E.

The following papers were "taken as read" :—(1) "A New Genus of Sponge from the Inferior Oolite," by H. D. Thomas, M.A., Ph.D., F.G.S. ; (2) "The Middle and Lower Barton Beds of the North-West Portion of the Hampshire Basin," by G. C. Colley.

Ordinary Meeting, 6th November, 1948.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

Miss Sylvia Barkley, Dr. Corydon Budge, Basil Staffurth Clarke, Arthur Raymond Crawford, James Chalmers Lamont, Andrew Richard Lang, John Harding McBride, B.Sc., Edmund Richard Martin, Henry Clifford Potter, Hamo Sassoon, Michael Townsend, Leonard Sambrooke Wilson, and Graeme George John Wingate were elected Members of the Association.

The Re-Union was then held in the Large Hall, Chelsea Polytechnic. For List of Exhibits, see below.

Ordinary Meeting, 3rd December, 1948.—Mr. E. Ernest S. Brown, M.B.E., F.G.S., President, in the chair.

William John Adams, Anthony John Arkell, M.B.E., M.C., B.Litt., F.S.A., Francis James Morey Archer, Gopal D'Arora, Kenneth J. Ashington, Theodore Robert Barnard, B.Sc., A.M.I.Min.E., Keith Edward Beer, B. Bentley, Sidney Leonard Birchby, Austin Brain, Hubert Whalley Bland, Richard Irving Canby, John Michael Carr, Ralph Percival Challener, Gerald Marcel Clarke, John Thomas Cleaves, B.A., Ronald Arthur Corbett, Geoffrey Cotton, B.Sc., F.Inst.Pet., F.G.S., Philip Werran Curnow, Alfred Robert Dailey, Edward Dale, B.A., Douglas Colin Davidson, Valence Chalinor Davies, B.Sc., F.R.G.S., Norman John D'Cruz, Robert Brian Elliott, Mary Dennis English, Lawrence George Evans, Geoffrey Walker Firth, B.A., Godfrey Herbert Francis, Wilfred Fry, George Roger Goodwin, Daphne Elizabeth Yorke Groom, David Salisbury Haig, B.Sc., F.G.S., Stuart Marshall

Hamer, B.A., A. Hammersley, B.A., Peter Raymond Hands, Tony Harris, Mrs. Hilda Kathleen Hawkes, Timothy T. Hinchin, B.A., R. E. Hodgkin, John Wentworth Holmes, William Hudson, Francis Edward Hughes, Richard Jeffries, Elgar Jones, Hugh Arthur Jones, Francis Thomas Jones, Harold Kear, Michael Philip Kerney, Guy Onslow Fairfax Kynaston, Professor Robert Léon Laffitte, Audrey Munro Lambert, Miss Joyce Layton, Alfred Ashley Leeming, Harold George Loe, Ronald George Maclean, Brenda McDonald, Professor George Marinoa, Arthur Marsland, Frederick Charles Ransome Martin, Jack Norman Martyn, Marcus Francis Clifford Martin, Ernest Mason, Edward Leon Philip Mercy, William Arthur Morley, Tom Morris, J. Myatt, C. Newton, Thomas Nixon, Miss Mary W. O'Malley, Miss Norah Mary O'Sullivan, Patricia Iris Papworth, Peter Hugh Phizackerley, Bryan Porteous, Herbert Daniel John Price, Thomas Samuel Purcell, B.Sc., John Francis Savage, Derrick Shaw, Margaret Myfanwy Shepherd, Michael Solomon, Sheila R. Stafford, Miss Dora Sylvester, David O. Thomas, Michael Alan Shaw Thomas, Mair Elizabeth Treharne, Reginald Aubrey Hoare Unthank, Harry Robert Warman, David Ian Watts, B.A., B.A.I., P.W.D., Oliver Willett, Douglas Harris Williamson, Ronald Winnett, Percival Walter James Wood, and Donald Henry Worth were elected Members of the Association.

The following lecture was delivered :—" International Geological Congress, London, 1948," by Professor H. H. Read, D.Sc., A.R.C.S., F.R.S., F.G.S.

LIST OF EXHIBITS

The President

Some rock specimens from Brazil.

The Librarian

The Association's Albums of Photographs.

Geological Survey and Museum

Recent Publications.

Geological Survey (Palaeontological Department)

- (a) East Anglian Pliocene Fossils recently acquired.
- (b) Some of the last known Trilobites to appear in Britain.

British Museum (Natural History)

- (a) Exhibit of original drawings by D. E. Woodall for British Museum (Natural History) Guide, "The Succession of Life."
- (b) A serial grinding instrument with ground sections of brachiopods. Demonstrated by W. N. Croft.
- (c) Fossil Ostracoderms and fishes collected on International Geological Congress "Vertebrate Palaeontology Excursion." Exhibited by H. A. Toombs.

Building Research Station

Reactive Aggregates in Concrete.

Chelsea Polytechnic, Geology Department

Specimens collected during the 1948 Field Season.

University College, London, Geology Department

Exhibit of Field Work carried out during the 1948 Field Season.

Anglo-Iranian Oil Co.

Air Photographs of Salt Plugs. Demonstrated by N. L. Falcon.

Bennett, W. H.

Marine fossils from the Berriasian (=Purbeck) of Cabra, Andalusia.

Bottley, E. P.

- (a) Exceptionally fine and unique crystal of Beryl.
- (b) Brazilian minerals.
- (c) New light-weight portable auger.
- (d) Hand-made geological hammers.
- (e) Portable field petrological microscope.
- (f) Swiss minerals.

Carreck, J. N. and Jones, D. E.

Fossils from some of the Jurassic Rocks of the Weymouth District.

Curry, D.

Examples of colour banding in Eocene and Oligocene Mollusca.

Davis, A. G. and Wrigley, A.

Selection of the Eocene fossils exhibited during the past 28 years.

Dollar, A. T.

Twelve years of recording by the British Earthquake Inquiry.

Gunner, A.

Lepidotus from the Weald Clay, Billingshurst.

Hayward, John F.

Conglomerates and Breccias collected during Field Meetings.

Jones, F. and Shearman, D. J.

Rock specimens, micro-slides and photographs relating to Syrian geology.

Junner, N. R.

Mineral specimens from West Africa, Morocco, S. America and Australia.

Lacaille, A. D.

Stone implements from Scottish Early Post-Glacial Raised Beach.

Moore, E. W. J.

Carboniferous *Goniatites*.

Rivett, W. H. E.

Bones of *Iguanodon* from Weald Clay, Ockley, Surrey.

Seal, K. E. and Kynaston, G. O. F.

Model illustrating Oxford Clay around Stewartby, Beds.

Snowball, G. J.

Selection of the Charnwood Forest intrusive rocks, together with the intrusive rocks of South Leicestershire.

Sprigg, Reg. C.

Photographs of Coelenterate impressions in Basal Cambrian Quartzite from South Australia.

Thomas, G.

Upper Devonian Fossil bands of *Craigynos*, Brecon, S. Wales.

Turner, J. G. and Venables, E. M.

Fossils from the London Clay, including a fossil beetle.

Wright, C. W. and Wright, E. V.

- (a) Neocomian *Belemnites*.
- (b) Cenomanian *Ammonites*.
- (c) Cretaceous *Holaster*

FIELD MEETINGS

All available Directors being engaged during August and September by the 18th International Geological Congress, it was decided to try and provide a full programme covering the period from March to July, and to arrange four week-end Field Meetings as partial substitution for the normal long summer meetings in August. These intentions, however, could not be carried out. A meeting which was proposed for Easter at Berwick-on-Tweed fell through, and no alternative could be arranged at short notice. A meeting which had been arranged for Whitsun at Cromer and Norwich received so little support from Members, that it was cancelled at the last minute. One further cancellation was imposed by the very high cost of road transport at the week-ends.

The following meetings took place :—

Saturday, 20th March.—Thirty Members attended a demonstration at the Imperial Institute.

Saturday, 3rd April.—The Fuel Research Board, East Greenwich. This was a morning meeting, and possibly on this account was but poorly attended, only 15 Members taking part.

Saturday, 10th April.—Drs. A. Morley Davies and Vernon Wilson directed a traverse of about 100 miles through the Chilterns. Thirty-five Members took part.

Saturday, 17th April.—Thirty Members attended a demonstration on the work of the Building Research Station at Watford.

Saturday, 24th April.—Dr. A. J. Bull (Weald Research Committee) demonstrated the results of mapping on the 25-inch scale of the slipped area at Tilburstow Hill, near Godstone. There were 25 Members at this meeting.

Saturday, 1st May.—A demonstration of the activities of the Rothamsted Experimental Station was given to 38 Members.

Saturday, 8th May.—Mr. W. S. Pitcher led a party of 27 to view the classic sections in the Lower London Tertiaries at Charlton, Plumstead and Lessness Abbey, Abbey Wood.

Sunday, 9th May.—Dr. J. F. Hayward demonstrated the geology of part of Epping Forest to a party of 30.

Friday, 17th to Monday, 17th May (Whitsun).—A very enjoyable week-end was spent by 32 Members at Lyme Regis under the direction of Dr. T. Barnard and Mr. J. G. Capewell. We were pleased to welcome Dr. W. D. Lang as Director on the morning of Saturday, 15th May. Miss E. J. Turner acted as Secretary.

Saturday, 22nd May.—Professor H. L. Hawkins conducted a party of 41 to Kingsclere.

Saturday, 22nd and Sunday, 23rd May.—Mr. E. M. Venables demonstrated the geology of Bognor and Bracklesham to 20 Members.

Saturday, 29th May.—In pouring rain, Dr. J. F. Kirkaldy (Weald Research Committee) demonstrated to 33 Members the stratigraphy and geomorphology of the North-West Weald.

Saturday, 12th June.—Two meetings were held simultaneously. Professor W. B. R. King with eight Members visited the section in Cambridge Greensand, Chalk and Chalky Boulder Clay at Barrington, near Cambridge.

Mr. A. G. Bell led a party of 24 to examine the topography of the Chalk of the North Downs and to see the Well Hill outlier.

Sunday, 20th June.—Mr. R. Casey conducted a party of 19 to the classic section in the Gault at Copt Point, Folkestone, and also

demonstrated recent work on the zonal relationships of the Gault and Lower Greensand at Sandling.

Sunday, 4th July.—In a raging gale and driving rain, Mr. T. W. Marsh took a party of 17 to study the coastline of Romney Marsh.

Saturday, 10th July.—A visit was paid by 22 Members to a new section in Gault at Greatness, near Sevenoaks, under the leadership of Mr. G. Austin Browne.

Sunday, 18th July.—Mr. E. C. Martin led 21 Members in a traverse from Goring-on-Sea to Findon.

Saturday, 9th October.—A demonstration was given by Professor F. E. Zeuner at the Institute of Archaeology, of an exhibition of Stone Age and Pleistocene Geology which had been arranged in connection with the International Geological Congress. About 100 Members of the Association, the Prehistoric Society of East Anglia and the Richmond Natural History Society were present.

Saturday, 27th November.—About 100 members attended demonstrations which had been arranged by Dr. G. M. Lees and Mr. P. Evans and their staffs in the Geological Departments of the Anglo-Iranian and Burmah Oil Cos. at Britannic House, Finsbury Circus, E.C.2.

Saturday, 11th December.—Forty Members availed themselves of the opportunity to pay a morning visit to the laboratories of Hunting Aerosurveys Ltd., Elstree.

MIDLAND GROUP

The following Meetings and Field Meetings were held :—

24th January.—Lecture : “ Glen Coe,” by Mr. W. G. Hardie.

28th February.—Lecture : “ Morphology of some Wenlock Brachiopods,” by Mr. F. B. Kelly.

29th May.—Field Meeting : Artesian well boring site in Edgbaston. Leader, E. J. Edwards.

26th June.—Field Meeting : Hartshill, Nuneaton. Leaders, A. F. Archer and H. Sanders.

25th September.—Field Meeting : The Wrekin. Leader, Dr. H. B. Whittington.

23rd October.—Lecture : “ Among the Tertiaries of Burma,” by Mr. H. M. Sale.

20th November.—Lecture : “ The Geology of the Normandy Beaches,” by Professor F. W. Shotton.

4th December.—Exhibition of colour photographs by Professor Wills, Mr. Hardie and Mr. Gillam.

NORTH-EAST LANCASHIRE GROUP

The following Meetings and Field Meetings were held :—

6th February.—Lecture, “The Victoria Cave,” by Mr. F. C. Bond.

19th March.—Lecture, “Sand dunes of the Lancashire Coast,” by Mr. J. Ranson, A.M.I.M.E., F.G.S.

16th April.—Lecture, “In the Kashmir Himalayas,” by Mr. McKelvey.

19th June.—Field Meeting : Longridge Fell and the Chipping Valley. Leader, Mr. J. Ranson, A.M.I.M.E., F.G.S.

3rd-4th July.—Field Meeting : With the Yorkshire Geological Society. The Clitheroe Succession. Leader, Dr. D. Parkinson.

26th September.—Field Meeting : Coplow and Belman Quarry. Leader, Mr. Westhead.

29th October.—Annual General Meeting. “The Geological Time Scale,” by D. H. Learoyd, B.Sc., F.G.S.

19th November.—Twenty-fifth Annual Address : “The Geology of Ingleton,” by Mr. J. Ranson, A.M.I.M.E., F.G.S.

DONATIONS TO THE LIBRARY DURING 1948

(The donors are the authors of the works presented, except where otherwise stated)

ALSACE ET LORRAINE, SERVICE DE LA CARTE GÉOLOGIQUE.—“Description et explication élémentaires de la carte géologique murale de l'Alsace et de la Lorraine,” by Dubois and Saurage (1948).

BERDINER, H. F.—“Outline of the Geology of England and Wales,” by W. D. Conybeare and W. Phillips (1822).

BIGOT, A.—“Géologie de la Région d'Honfleur” (1947) and four other pamphlets.

COLLET, L. W.—“La géologie du versant sud du massif de Gas-tern” (1948).

CONGO BELGE ET RUANDA-URUNDI, SERVICE GÉOLOGIQUE.—“Bulletins” Nos. 2 and 3 (1947-8). Also “Compléments à la Bibliographie Géologique de l'Afrique Centrale. Congo Belge,” by A. Jamotte (1948).

COTELO NEIVA, J. M.—“Rochas e minerios da regio Bragança-Vinhais” (1948) and three other pamphlets.

- DACK, W.—“Map of the Corallian Beds around Highworth, Wilts.”, by W. J. Arkell (1941) and “The Evolution of Indian Geography,” by R. D. Oldham (1894). Also four other pamphlets.
- DALY, R. A.—“The Vredefort Ring-Structure of South Africa” (1947) and “Coral Reefs—a Review” (1948).
- DAVIS, A. G.—“William Smith, Civil Engineer, Geologist” (1948).
- GEOLOGICAL SURVEY OF GREAT BRITAIN.—“British Regional Geology,” 12 handbooks (1946-8). Also Memoirs, “Dudley and Bridgnorth,” by T. H. Whitehead and R. W. Pocock (1947) and “Southport and Formby,” by D. A. Wray, F. W. Cope and others (1948).
- GOSKAR, MISS K.—“A Coloured Geological Map of the Principal Features of the Geology of Yorkshire,” by J. Phillips (1853).
- JACKSON, J. W.—“The Upper Pleistocene Fauna and its Relation to the Ice Age” (1948) and “*Tylonautilus nodiferus*” (1948).
- MARSHALL, C. E.—“The Significance of Geological Science for the Modern World” (1947).
- OVEY, C. D. and W. S. PITCHER.—“Observations on the Geology of East Suffolk” (1948).
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OBITUARY NOTICES, 1948

MRS. H. H. BEMROSE died on the 7th October, 1947. She joined the Association in 1899, the year in which her husband, Dr. H. H. Arnold Bemrose, gave a classic paper on the lower Carboniferous Rocks of Derbyshire and was the chief director of the Long Excursion. Her own work and interest was mainly educational. She was for some years on the County Educational committee and became well-known throughout the country as Secretary of P.N.E.U. She was joint author with her husband of the "Cambridge County Geography" of Derbyshire.

DR. ANANDA K. COOMARASWAMY, a life member of the Association, a Fellow of the Geological and Linnaean Societies and of University College, and a member of the Royal Asiatic Society, died at Boston, Massachusetts, on 9th September, 1947. Son of the late Sir Mutu Coomaraswamy of Ceylon, he was born in 1877, and educated at Wycliffe College and University College, London. His undergraduate career was a brilliant one. He had passed the Intermediate examination in Arts before entering College, but there he studied Science, winning the Jews' Commemoration Scholarship, a gold medal for Botany and a prize for Mechanics. He was only disqualified by age for scholarships in Botany and Geology, which he studied under Prof. Bonney. His other subjects included Mathematics, Physics and Chemistry. In 1900 he won his B.Sc. with first-class honours in Botany and Geology. Meanwhile he had become an active member of our Association. Elected to membership in June 1896, he led several excursions to Guildford and Godalming, exhibited at our conversaziones in 1899 and 1901, and published a paper on Fish Teeth in the Bagshot Sands in the *Proceedings* for 1903. During the same period a series of his papers appeared in the *Quarterly Journal* of the Geological Society, dealing chiefly with the minerals and rocks of his native Ceylon, but his interests extended to India, Brittany and the Hebrides.

In 1903 he became Director of the Mineralogical Survey of Ceylon, a post he held till 1906, and during these years a series of official reports flowed from his pen. In 1906 he gained his D.Sc. in Geology.

But his interests were changing. He initiated a movement for national education in Ceylon, the teaching of the vernaculars in the schools and the revival of Indian culture, and to further these ends he became President of the Ceylon Social Reform Society. His first book, *Mediaeval Sinhalese Art*, published in 1908, was a homily on the ills of modern art and society, and a plea for the revival of the ancient traditions of India, and thereafter he was led to explore these traditions more and more deeply. In 1910 he helped to found the India Society, of which he became Vice-President, and in the same year he was in charge of the Art Section of the

United Provinces Exhibition. His ever-widening interests led him back to University College for the session 1911-12 to study Icelandic. Other authoritative works on Indian and Sinhalese art followed, and in 1917 he was appointed Keeper of Indian, Persian and Muhammadan Art in the Museum of Fine Arts, Boston, Mass., where he built up the first really representative collection of Indian art in the West. In his writings he would always look beyond a work of art itself to its significance in a wider connotation. It has been said of him that "he was, and looked, more a prophet than a professor ; and he brought to our present problems the fruits of his interpretation of Indian aesthetics and theology in terms intelligible to the West."

[L.J.C.]

CECIL COOKE DUNCAN was born at Lee, near Lewisham in Kent, on 5th April, 1868, and died at Worcester on 4th October, 1948. He was a son of Prof. P. M. Duncan, M.D., F.R.S., who in his day was a well-known palaeontologist. Duncan was educated at a private preparatory school, King's College, London, and the University of Strasbourg. He was First Assistant to the Professor of Chemistry and Lecturer in Bacteriology, Royal Agricultural College, Cirencester, Glos., from 1893-8, and Public Analyst to the Worcestershire County Council, and to the City of Worcester (two separate appointments) from 1898 until 1936, in which year he retired.

Duncan was a F.R.I.C., F.C.S. and F.R.M.S. He was much interested in Geology (becoming a member of this Association in 1904), in Botany, and in church architecture, particularly of Herefordshire. Also in Zoology : in his earlier days he had a table at the Marine Biological Station at Naples for three months, where he worked on the quantities of oxygen required by various fish, but later his professional duties left him practically no time for research. He was a very conscientious official : he was not a "bird of passage," but settled down in the county he was appointed to serve, and found his recreation in studying its geology, botany and archaeology to the advantage of kindred spirits with whom he came in contact. He contributed the section on "Water Analyses" to the Geological Survey memoir, the "Wells and Springs of Worcestershire" (1930), in which he gave a great number of chemical analyses that convey a good idea of the nature of the well-waters from the many geological formations present in the county. He took great practical interest in the Worcestershire Naturalists' Club : he organised and led a number of its long field meetings ; he was president from 1928-31 and from 1938-46 ; was made an honorary member in 1947, and contributed a number of interesting Presidential Addresses and papers to its *Transactions*. He is survived by his wife : there were no children of the marriage.

[L.R.]

ALFRED SANTER KENNARD, our president in 1944-6, died peacefully in his home at Beckenham on 11th June, 1948, towards the end of his 78th year. Although he was born during the Franco-German conflict, his active life did not lie in the shadow of impending war, and he was elderly when the value of money began to be unstable. Free from these cardinal distractions, his life, uneventful and, in a worldly sense, unambitious, was on firm ground where he could follow the direction of his natural inclinations without staggering amidst moral and social earthquakes. After what would now be called a sound elementary education, he earned his living in a large City warehouse, remaining there until his retirement. He worked there for 44 hours a week, with a fortnight's summer leave, and the usual Bank holidays, so his leisure was far from ample, but it was all devoted to the studies and tastes which had attracted him in youth—natural history, antiquities and the collection of relics of the past, which gradually filled his home. He had no academic training in his chosen subjects, but he could, and did, read and associate with men of like minds.

Sixty years ago the antiquity of Man, although soundly established, had an attraction of novelty now inevitably lost, and Kennard's dispersed interest in nature and bygone men seemed to crystallise around this subject, so that he became a specialist in Pleistocene geology and palaeontology, although he had made a fine collection of Crag mollusca, which later on was given to F. W. Harmer. About 1897 he became associated with B. B. Woodward in a series of papers on the post-Pliocene mollusca of England, several of them being published in our *Proceedings*. In the first fruit of this collaboration (*Essex Naturalist*, 10, p. 92) they introduced the term *Holocene*, now generally used. Kennard has left a note explaining that the word was suggested by a working man to Dr. Henry Woodward, as editor of the *Geological Magazine*, and by him passed on to them. Later they found that the word had been earlier used in France, but ignored. In 1905 he joined M. A. C. Hinton in a paper on "The relative ages of the stone implements of the Lower Thames Valley" (*Proc. Geol. Assoc.*, 19, p. 76), which greatly stimulated the study of its subject. During his last years Kennard compiled a bibliography of his printed papers and notes (excluding all contributions to the Press), which reaches a total of 250 items, commencing in 1895 with an illustrated note on the Pleistocene mollusca of Crayford and ending in 1945 with a note in the *Essex Naturalist* on the Holocene mollusca of Takeley. A typed copy of this bibliography may be seen at the offices of the Geological Survey, and it will show how a large part of his work was published in appendices to the memoirs produced by other people. Those who conducted archaeological excavations always sent their mollusca to him for determination and report, and in this way he was able to trace the changes in

England's molluscan fauna from Neolithic to Saxon times, thus filling what was a mere blank in our knowledge. Another large part of his publication was devoted to living land and freshwater mollusca and to their nomenclature. Pleistocene vertebrates naturally attracted Kennard's attention, particularly as a collector, and he was associated with all those of his time who have studied them. Besides thinking, in good company, that the Kentish eoliths were artefacts, Kennard maintained the minority opinion that the only unequivocal palaeontological evidence of an intensely cold period in the English Pleistocene was found, towards its end, in the Lea Valley Arctic bed. Living to a ripe age, he became a valuable link with the geological workers of past generations and, as a humorist, he was not above some harmless gossip about those personal peculiarities which make people real. Apart from these personal reminiscences, he had known and learned from so many able men that his juniors were impressed by the extent and variety of his information. He joined our Association in 1894, received its Foulerton Award in 1923, and was the first recipient of the Stopes Medal, in 1946. He felt highly honoured by becoming our president, and regarded his tenure of the office as the crown of his career.

The Geological Society awarded to him the Lyell Fund in 1916 and the Prestwich Medal in 1945. He was an Associate of the Linnean Society, president of the Conchological Society in 1927-8 and of the Malacological Society in 1922-5. His life shows us what can be done for the advancement of knowledge by an entirely self-trained man of very limited leisure and quite modest means.

Complementary notices will be found in current publications of the Geological Society, the Conchological Society and the Malacological Society, the last having an excellent portrait of Kennard as a frontispiece to vol. 28 (1928) of its *Proceedings*.

[A.W.]

Major H. W. LEWIN, M.A., A.M.I.C.E., A.M.I.Mech.E., was born on 2nd July, 1879, and died in October, 1947, having been a member of the Association for 37 years. He was educated privately, and commenced his career as a pupil to the London and North-Western Railway Company, serving his time at Crewe. On completion of his apprenticeship he went up to Cambridge, to Clare College, and after taking his degree became a pupil on the Great Northern Railway. Later he worked on the extension of the Enfield line and on the Tickhill light railway.

During the 1914-18 war he held a commission in the R.A.S.C., in the Mechanical Transport section, and at the end of the war he was transferred to the India Office, where he did similar work, chiefly in connection with armoured vehicles.

At the beginning of the last war (when over 60) he was called up

and served for two years. Being over military age, he was subsequently employed by the Ministry of Supply.

Geology interested him deeply, and his knowledge of it helped him when he was surveying for the construction of the railways and on other engineering work ; it also added interest to holidays and his visits abroad.

[W.D.]

LUCY SHEILA MACCARTHY MORROGH was born at Kinsale, Co. Cork, on 21st June, 1913. She arrived in England in 1934, and studied geology at Chelsea Polytechnic. She became an enthusiastic member of the Polytechnic's Geological Field Club, and joined the Geologists' Association in 1940. For a while at the beginning of the war she was a member of the Auxiliary Fire Service. Later she took a post in a chemistry research laboratory, but she preferred geology and at the end of the war joined the Water Department of the Geological Survey. Ill health now began to overtake her, and on 2nd May, 1948, she passed away at an early age.

She will be remembered by all who knew her as a very dependable friend. As a geologist her keenness knew no bounds.

[R.E.B.]

In Mr. E. J. PEGG, F.G.S., we have lost a beloved and useful member, who died in November, 1948, at the early age of 51. Though a very successful manufacturer, he was early thrilled by the geology of the Midlands, and he joined the Birmingham Nat. Hist. and Philos. Society in 1932. Of the geological section of this he was Secretary from 1938 till, owing to enemy action early in the war, its rooms went up in smoke. He had joined the Geologists' Association in 1933, and was elected a Fellow of the Geological Society in 1937. In this year also he was the prime mover in securing the establishment of our Midland Group, which he has always generously supported. Cave hunting also claimed his interest, and he was an active member of the Speleological Club.

[F.R.]

Dr. JOHN PRINGLE, formerly Palaeontologist to the Geological Survey and Museum, was a member of the Association for 29 years, which included two periods of Council service. He died on 2nd August, 1948. A well-built man of slightly above average height, he had a genial personality which gave him a wide circle of friends.

To our *Proceedings* he contributed three papers. In 1924, "A Synopsis of the Geology of the Boulonnais ; including a Correlation of the Mesozoic Rocks with those of England," written with Professor P. Pruvost ; "The Geology of Ramsey Island (Pembrokeshire)" and in collaboration with Dr. R. Crookall

“The Palaeobotany of the Kent Coalfield,” both of the latter in 1930. He also contributed a number of reports of field meetings, for he was active in such leader- or co-leadership.

Born at Selkirk in 1877, he left school at an early age, and had a hard time with frequent changes of employment until he joined the Geological Survey in 1901 to work under E. T. Newton in the grade then styled “Fossil-collector.” His early duties took him to the South Wales Coalfield with its neighbouring regions in nine of his first 10 years of Survey life ; during these years he married Miss Margaret Davies, of Gat Goch, Carmarthenshire (1906), who survived him only by three weeks. He also collected in North Wales and in most of the English midland and southern counties. His official collections at South Kensington alone number over 27,000 fossils ranging in age from Cambrian to Tertiary. In 1913, Pringle was promoted to the post of Assistant Palaeontologist, and his principal work became determinative palaeontology, though he personally collected from an even greater number of cored borings than he had previously. In 1919 he was awarded the Lyell Medal by the Geological Society and he joined our Association. In the year following, in collaboration, he led two excursions ; the first with W. H. Booth was to the site of a water-boring at Cippenham near Slough, and the second with F. L. Kitchin to study Cretaceous sections at Leighton Buzzard ; this last was memorable as the scene of considerable discussion concerning the age of the remarkable limestone examined at Harris’s Pit on Shenley Hill. Pringle acted as co-director of three excursions to Swindon, the first and last being in 1921 and in 1936, and both were with Messrs. C. T. Gore and C. P. Chatwin, and another in 1923 at Easter with Professor H. L. Hawkins. The first long excursion which he led was with Professor P. Pruvost to the Boulonnais in the summer of 1923 ; and in 1926 he conducted a week-end field meeting to Oxford. Towards the end of 1928 Pringle was transferred to the Edinburgh office of the Geological Survey, and in the following year he acted as one of the four leaders of the East Sutherland summer field meeting. In 1930, however, he journeyed south to join Professor A. H. Cox, Mr. J. F. N. Green and Professor O. T. Jones as leaders of the summer field meeting to the St. David’s district. Pringle’s services to the Association were recognised in 1931 by the presentation to him of a moiety of the Foulerton Award, and in that year also he received the honorary degree of Doctor of Science from the University of Wales.

Though not an official leader on either the Ardnamurchan or the Girvan Summer Excursions of 1932, the excursion reports of both affirm Pringle’s contribution to the success of the meetings.

He returned to London as Palaeontologist in 1934 and took an important part in the removal of the collections of fossils from the Jermyn Street building to that in Exhibition Road and subse-

quently he arranged the South of Scotland regional bay on the north side of the second floor in the museum, writing at the same time the Guide to that region which contained his birthplace. Few of his 60 or more publications gave him greater pleasure to write. Subsequently he undertook similar duties for the older systems of South Wales, and the remainder of that region was dealt with by Professor T. N. George. Pringle lived long enough to take part in the revised editions of these two regional guides and to see these published in 1948.

The last summer field meeting which Pringle led took place in 1937, the year of his retirement from the Geological Survey, and, although this Dumfries excursion had six directors, Pringle's share was considerable.

Pringle spent his retirement in Scotland and retained to the last his enthusiasm for his subject, devoting many long hours to searching for fossils where none had previously been found, and he was not unrewarded, particularly in Leny Quarry, Callander. His searches led him repeatedly to the western isles of Scotland, and there is little doubt that the arduous conditions in which he searched hastened his end. He was a Fellow of the Royal Society of Edinburgh, and he had a period as president of the Geological Society of Edinburgh. In London he had served on the Council of the Palaeontographical Society, of which he was a vice-president, also on the Council of the Geological Society; from the latter Society, in 1935, he received the Lyell Medal.

[C.J.S.]

DR. R. L. SHERLOCK was born on 26th August, 1875, the younger son of Thomas Sherlock, a pharmaceutical chemist, in St. Helens, Lancashire, where he received his early education and must have been first inspired with his interest in geology. In 1897 he won a Royal Exhibition, which enabled him to shape his career to his liking by proceeding to the Royal College of Science at South Kensington to take the course in geology under Prof. Judd. The Associateship of the College in 1900 was followed by the external degrees of B.Sc. and D.Sc. of London University.

Attachments, whether to pursuits or to friends, formed by Dr. Sherlock, were long-lived. At South Kensington he came under the inspiring influence of Frederick Chapman and took a keen interest in foraminifera which was to last his life-time, though he wrote but few, short papers about them. They maintained their friendship until Mr. Chapman died in Australia after a long curatorship of Melbourne Museum. On leaving South Kensington in 1902, Sherlock took the post of Science Master at Portmadoc as a stop-gap until he could achieve his desire, fulfilled early next year, of joining the Geological Survey.

So young Sherlock joined Teall, H. B. Woodward, Fox-Strangeways, Strahan, Reid, Barrow, Lamplugh and other Victorians at the Survey office in the Jermyn Street Museum, to work directly under most of these in turn before they retired. Independent and rather angular, far from wearing his heart on his sleeve, he made few friends, whether among equals or seniors, and suffered in consequence. But though promotion passed him by, his spirit remained unbroken and his devotion to his work was unaffected.

Being an ascetic monk of the hammer, stories gathered round him, as that he was tempted to take a wife just when Davies Sherborn's unique library on foraminifera was for sale. Unfortunately the price of the library made it impossible for him to indulge in both wishes. The story was doubtless a yarn, but he bought the library. He enjoyed the stories as much as we did, or even more, as in the result of his alleged determination to complete his service on the Survey, which finally amounted to 34 years, without taking a day's sick-leave—no mean testimony alike to his devotion to duty and his constitution. The presence of the "Doctor" with a bad cold in the crowded Top Office, determined not to stay at home, squarely put the joke on us.

For the first five years in the Survey he worked largely on the Permian and Triassic succession bordering the Nottinghamshire coalfield. In his very first year the intimate relations, amounting to partial equivalence, of the Permian Red Marl to the Triassic Bunter Sandstone struck him as anomalous if the one were Palaeozoic and the other Mesozoic. The anomaly started his investigation into the evidence elsewhere on which the Permian System was based, an investigation which was continued, as opportunity served, throughout his life. His Survey work—he became an authority on these systems—enabled him to examine the chief outcrops in this country, but he found that anomalous "Permian" formations were world-wide. Concerning these he gradually gathered up the published facts and views for full presentation of all the evidence in book form. Besides writing this book Dr. Sherlock made use of his knowledge of the Permian and Trias of this country in several papers on their problems and stratigraphy, and notably in the Special Report of the Survey on their chief mineral products, rock-salt and brine. Probably impressed by the extent of the subsidences caused by the abstraction from the earth of coal, salt and other rocks by man, in 1922 he followed up the Special Report with a semi-popular work, which he dedicated to his mother, on *Man as a Geological Agent*. This book, like his other, is an example of his unusual capacity for hunting out and assessing all available data bearing on a problem.

Except during the war years, 1915-18, which were occupied on mineral resources, his mapping from 1910 to 1921 lay in the wide London area, for which he prepared the Regional Handbook and an exhibit of specimens, illustrations, etc., in the new Geological

Museum at South Kensington. At his suggestion his friend, E. Marsden Wilson, painted in oils two imaginary scenes vividly portraying shores of the London Clay sea and the Wealden lake. For the Museum also Dr. Sherlock has designed a model, an illuminated "Geological Column," on each of the five sides of which are shown to scale the geological systems with their distinguishing features.

With the opening of the Manchester office of the Survey in 1921 Dr. Sherlock returned until 1930 to his native county, eventually to his native town. During this period he did much to stimulate local interest in geology. Thus he was largely instrumental in founding a branch, the North-East Lancashire Group, of the Geologists' Association. For this service and for his original contributions to the science he received the Foulerton Award in 1931 and was elected Honorary Member in 1937. He retired from the Survey in 1937 with the rank of Senior Geologist.

During these years he continued to work at the Permian question. In order to see Gondwanaland and its deposits at first hand he visited South Africa in 1929 with the International Geological Congress and South America in 1933. His exchange of views with geologists of other countries, especially with Dr. A. L. du Toit, his friendship with whom continued to his death, did much to widen his outlook.

Retirement found him with the book which was his life-work still lacking a publisher, and without illustration and the vital references (which when printed filled 19 pages) unchecked. Shortly his splendid health began to fail, and then the war came. His great courage rose to a sombre height when, alone in his home in Kew with a dying sister, without help or possibility of shelter from bombs for a period to which he saw no early end, he nursed her until she died, the while steeling himself to finish, in odd scraps of time, his book. He and his good friends, H. Dighton Thomas and C. P. Chatwin, the latter of whom checked the references and later took over everything, grimly held on. The book, *The Permo-Triassic Formation: a World Review*, was finished and, after a harrowing delay, appeared.

The rapid advance on him of one of the most dreadful diseases, though unnerving enough to an onlooker, might have been borne by himself easily, but for his fear that he would not see his book published. Soon after he had seen and handled it, he died on 18th January, 1948.

By the time he retired he had made a modest fortune by shrewd investment of his savings, which, in his sympathy with "under-dogs, animal and human," he left to the People's Dispensary for Sick Animals of the Poor.

Our science lost by his death one who worked, consciously and unconsciously, for its advancement in various ways, but with unusual singleness of purpose and courage.

[E.E.L.D.]

A STRUCTURE CONTOUR MAP OF THE SURFACE OF THE BURIED PRE-PERMIAN ROCKS OF ENGLAND AND WALES

By P. E. KENT, Ph.D., F.G.S.

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SUMMARY

Incorporation of the new information made available as a result of exploration for petroleum with pre-existing data from other sources makes possible construction of a generalised contour map of the surface of the buried pre-Permian rocks of England and Wales.

The available deep well sections are still somewhat irregularly distributed, but the data are sufficient to show the marked structural contrast between different parts of the country which may be summarised as follows :

1. In north-eastern England the gentle slope known in the concealed coal-field continues to the North Sea coast, the sub-Permian wave-cut platform having remained essentially stable except for progressive eastward tilting.

2. North-western England shows a series of very deep basins whose margins are formed by a combination of faults, monoclines and ancient scarps. As in the north-east, there is evidence that the basins developed progressively through Permian and Mesozoic times.

3. The south Midlands, where the buried "London Platform" is developed, appears to be a remarkably flat, unfolded, high-standing area. Charnwood and the Warwickshire Coalfield appear as a spur of this massif.

4. Southern England appears as a downwarped area in which a broad deep basin extending from the Cotswolds southwards to Dorset and eastwards to Kent has been modified by Tertiary folding. It is suggested that this might be called the "Wessex Basin" following the ancient name for the region.

The map brings out also the homologous character of the Malvern "fault" with the faults and monoclines bounding the deep basins of north-western England ; the form of the narrow trough which crosses the southern end of the

Pennine uplift and severs it from the Midland coalfields ; the presence of a thick Mesozoic sequence in north Norfolk ; the regionally subsidiary character of the Mesozoic Mendip "axis" (the Mendips appearing as a shelf-like projection of the Welsh Highland) ; and finally the development along the south coast of generally east-west upfolds which partially separate the Wessex Basin from the Channel syncline.

I. INTRODUCTION

VARIOUS authors have constructed contour maps of the base of the Permian or Mesozoic rocks in small areas, for example in coalfield areas where depth to Coal Measures is important, and in south-eastern England where numerous borings have reached pre-Permian rocks. The deep basins of north-east, north-west and southern England have, however, remained until recently unplumbed areas in which it was only possible to speculate about thicknesses of formations. The present oil search campaign has now provided information of great value in certain of these basins, and it is possible for the first time to attempt a contour map of the whole country. In addition, the production of *Well Catalogues* by H.M. Geological Survey has now made easily available an important body of data from borings for water and other minerals, extending and bringing up to date the valuable compilations published in *Water Supply Memoirs* and in *Thicknesses of Strata* (1916).

For this work a scale of ten miles to one inch was chosen as most convenient for the base map, and a reduction to half scale (twenty miles to one inch) accompanies this paper. Five hundred feet is used as the contour interval, as giving a clear picture without demanding more detail than can be supplied for the greater part of the country.

The map (Plate 2) was originally produced as a contribution to the investigation of the underground structure of England by the D'Arcy Exploration Company. It has been submitted for publication, at the suggestion of Dr. G. M. Lees, by kind permission of the Chairman and Directors of the Anglo-Iranian Oil Company Ltd. Warm thanks are due to Dr. Lees, Mr. F. D. S. Richardson and Mr. N. L. Falcon of this Company for their careful consideration of the manuscript and for a number of valuable comments.

II. REGIONAL DESCRIPTION

In the following paragraphs the more important items of evidence are mentioned, and some of the more interesting features of the regions discussed. The evidence of the post-Carboniferous development of the basins is briefly outlined in each case.

(a) North-eastern England

(i) General Structure

The remarkably even eastward slope of the Permian in Nottinghamshire and south Yorkshire has been recognised for many years

in the coalfield areas, and although recent exploration has shown minor irregularities locally, the general simplicity remains between York and Nottingham. In Durham also boring records indicate an almost equally regular arrangement.

In east Yorkshire there is a little more irregularity, produced by the east-west Cleveland fold and by north-south folds near Eskdale and Whitby. For the present map, the structural map of the Dogger in east Yorkshire by F. D. S. Richardson (Lees and Cox, 1937, Fig. 2)* was used as a basis. Using the Eskdale and Cleveland Hills boreholes as control points, the Dogger contours have been adjusted for the greater fall of the base of the Permian on the evidence of thickness changes between these two wells. The pre-Permian surface at Eskdale is assumed to be only a short distance below the lowest horizon reached there, for the Cleveland Hills borehole indicates that there is a marked eastward attenuation of the Permian basement beds which is likely to persist as far as Eskdale.

No information seems to be available about the depth of the Pickering syncline, but the evidence of south-westerly attenuation towards Market Weighton leads to assumption of the general strike to be north-west-south-east on the base of the Permian.

The recent (1946) boring at Hayton, near Pocklington, has shown that the Market Weighton structure is not associated with any major swing of the contours, for the Permian and Trias are both fully developed. Seismic survey has however confirmed the fact that the minor folding of the Lias is reflected at depth in the Permian, so that there is less regularity in detail than is found, for example, in the concealed east Midland Coalfield area. The small flexures are partly north-south and partly east-west, but they show no obvious relation to the intra-Jurassic uplift or to the broad Wharfe fold.¹

In Lincolnshire boreholes now show that the even easterly dip continues into the Fenland, and there is no reason to assume any variation in the easternmost part of the county. Deep borings in the Midlands and southern East Anglia long ago showed that there must be a swing of these contours from north-south to east-west in the neighbourhood of the Wash, and the North Creake boring now provides an accurate control point for north Norfolk, where Jurassic and Triassic rocks are both well developed (Kent, 1947).

(ii) *Development of the Basin*

The Mesozoic history of the area falls into two distinct phases. Throughout the Permian and Triassic periods eastern Yorkshire, Lincolnshire and the adjoining counties formed part of a single depositional basin, while during the Jurassic and early Cretaceous

* For list of References, see p. 101.

¹ The Hayton boring entered Lower Coal Measures beneath the Permian, suggesting that the strike of the Carboniferous rocks continues unchanged from the Leeds district to the Chalk outcrop. It indicates that the general structural rise terminating the coalfield on the north (a rise with which the Wharfe anticline is associated) is developed as far east as Market Weighton, but it does not establish the presence of a pre-Permian *anticline* there.

they were separated by the Market Weighton block, over which all formations between the Keuper and Gault are attenuated.

The Permian is the formation most widely penetrated by borings, and its variation illustrates admirably the way in which contemporaneous subsidence contributed to the development of the north-eastern basin (Fig. 7). The Bunter similarly thickens eastwards as far as exploration has extended, but the Keuper—with a much slower thickness change—reaches its known maximum in the Lower Trent Valley. The Rhaetic shows a maximum coinciding with that

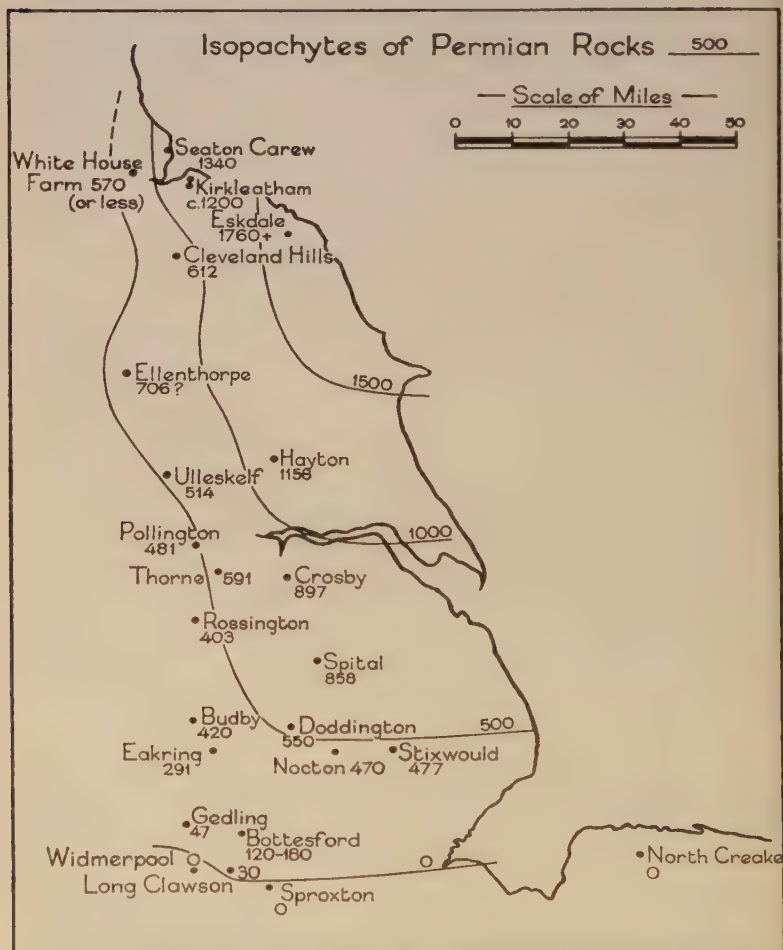


FIG. 7.—THICKNESS OF THE PERMIAN ROCKS OF NORTH-EASTERN ENGLAND.

of the Keuper, but it differs in being the first formation to be appreciably affected by the development of a stable area around Market Weighton.¹ From this time onwards each subdivision became attenuated in south Yorkshire and, although there is evidence of largely continuous connection over or round the stable area, intermittent erosion during Jurassic and Cretaceous times removed the greater part of the deposits there. In the Jurassic Yorkshire Basin the beds reach their maximum on the coast in the Whitby-Scarborough area. In Lincolnshire the Lias appears to be thickest near Grantham, with a subsidiary maximum near (just west of ?) Lincoln. The later Jurassic clays are best developed in central Lincolnshire on the northern edge of the Fens.

In south Lincolnshire and north Norfolk the marginal deposits of the basin still exist. Farther south each of the pre-Gault formations thins out and becomes truncated or overlapped by later beds, so that finally the Gault comes to rest on pre-Permian rocks.

(b) North-western England

(i) General Structure

North-western England contains a series of Mesozoic synclines—the Solway Basin, the Vale of Eden, the West Lancashire Basin and the Cheshire Basin—which are characterised by their relatively great depth and sharp margins. To some extent the margins are formed by faulting, but the extent of this has been questioned in some cases, and both overlap and stratigraphical thickening play a part in the incoming of the post-Carboniferous deposits. For the present map the basins have therefore been drawn as having steeply shelving floors at the margins, except in particular cases where very large faults are clearly defined, this being a generalisation intended to cover the probable combination of groups of faults, overlaps and stratigraphical thickening. The irregularity of the pre-Permian surface on the margins of the basins, which is in marked contrast to the wave-cut platform of north-eastern England, may well extend over parts of their floors, but data are too scanty to show it.

In the Solway Basin borings have proved Trias to a depth of approximately 1000 feet below sea level. The thicknesses of the St. Bees and Penrith sandstones, however, are not accurately known, and judging from the figures in west Cumberland and Lancashire (see below) the depth to the pre-Permian would be at least 3000 feet and possibly as much as 5000 feet in the central parts.

In the Vale of Eden the Penrith sandstone with the Brockrams is believed to be of the order of 2000 feet thick, and we are indebted to Professor Shotton for the information that the beds above measure

¹ The writer prefers to avoid the terms "axis" and "anticline" for this structure, regarding these as implying an unjustifiable association with folding and orogenic movement. Drawings to scale of the behaviour of the Jurassic rocks over the critical area show it to have been a relatively rigid and unfolded area through most of Jurassic times.

rather more than this. In relation to its width this faulted depression therefore appears as the most trough-like of the basins of north-western England.

Geographically, the West Lancashire Basin is divided into three parts by the inlets of Morecambe Bay and the Ribble Estuary. The northernmost section, in the Furness area, has a strongly faulted eastern margin. Two faults, the Yarlside and Whinfield faults, have throws of the order of 2000 feet, and a third, the Gleaston fault, is also of major importance. The Permo-Triassic sequence totals well over 4000 feet, despite the absence of much of the Keuper, and this together with the absence of interbedded screes in the upper part suggests that the original edge of the basin lay some distance to the east, on the site of the pre-Permian outcrops. In this respect the Furness area contrasts with the part of the basin south of the Ribble, for there relatively attenuated Permo-Trias surrounds the pre-Permian outcrops. The pre-Permian surface is likely to be some 4000 to 4400 feet deep on Walney island, and it is still at 2789 feet below sea level at Barrow-in-Furness on the upthrow side of the Whinfield fault.

In the coastal plain, south of the Ribble, no deep boring records are available. Shallow borings in and near Preston however show the Trias to be thin, indicating that the boundary fault system is not well developed there. Faults farther west may, however, have contributed to the development of the basin.

In the Formby-Ormskirk area our deep borings have shown the great depth of the basin which underlies the Lancashire coast; they demonstrate also that the depth is far greater than the probable throw of the boundary faults, and that the subsidence of the basin must have been considerably affected by basin-ward thickening of the sediments, as well as by additional faults within the Triassic outcrop.

The distribution of the contours in the neighbourhood of the Lancashire and Cumberland coasts leaves no doubt that the Irish sea overlies a very deep Permian-Mesozoic basin, the existence of which was previously suspected from the occurrence of Jurassic fossils in drifts of north Wales. It is possible that the Isle of Man represents a part of the opposite margin of the basin, or—in view of the presence of saliferous Trias at the northern end of the island—perhaps more probably an isolated massif or a post-Triassic horst.

The depth of the Cheshire Basin is largely a matter of surmise. In the Northwich-Knutsford area the deepest borings only just reach the base of the Keuper at 2500 feet, and there is no direct information on the thickness of the Bunter and Permian. We have, however, an idea of the minimum thickness of the Keuper from these borings, and it is provisionally assumed that the Bunter is about the same thickness as at the nearest outcrops. This may be a conservative estimate, for Trotter (1945) has pointed out that there is a tendency for the members of the Permo-Trias to thicken basin-wards.

Identification of datum planes in the Keuper has indicated that the deepest part of the basin is in the Northwich area and is elongated in a general west-north-west-east-south-east direction, thus showing the influence of the syncline which produces the saddle of Wirral and south-west Lancashire, connecting Cheshire with the Irish Sea Basin. Shallowing south of this is indicated by the rise of the salt beds to surface in the Nantwich area.

The presence of a Lias outlier at Prees indicates that the basin has a southern "deep" in north Shropshire, which, as the Bunter on the

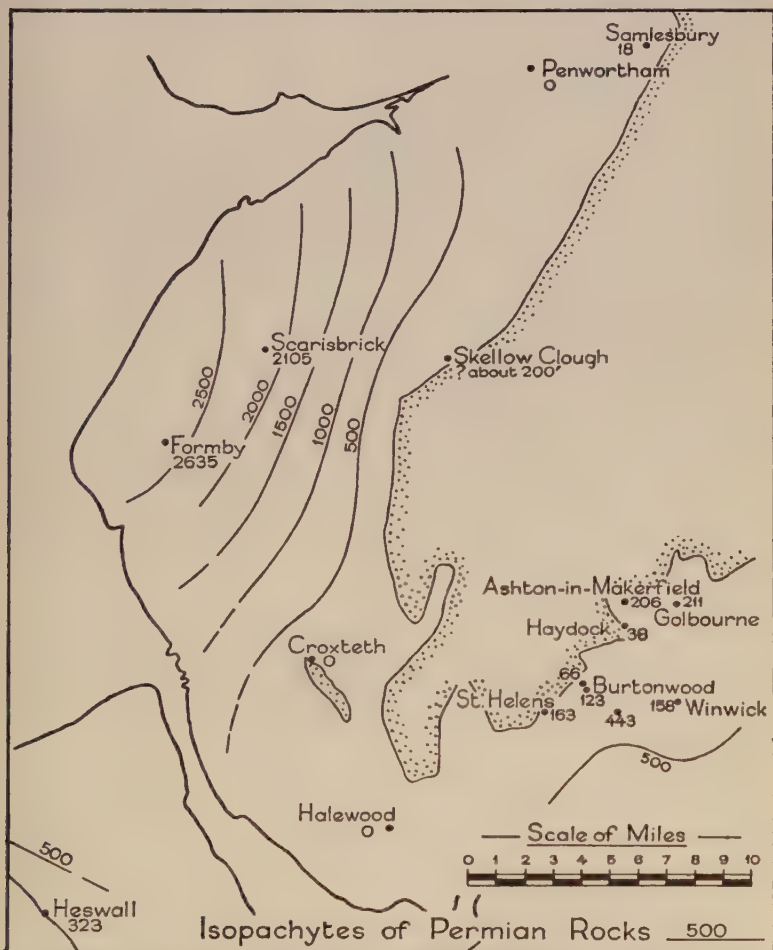


FIG. 8.—THICKNESS OF THE PERMIAN ROCKS (MANCHESTER MARLS WITH COLLYHURST SANDSTONE) IN WEST LANCASHIRE.

neighbouring margins of the basin is not known to approach the thicknesses of north Cheshire, is assumed to be appreciably shallower than the northern deep, notwithstanding the greater completeness of the succession.

As in the west Lancashire section of the Irish Sea Basin, there is evidence that the incoming of thick Trias in Cheshire is due to a combination of marginal and other faults together with steep dips and overlaps, the detail of which is not yet worked out. It has therefore been considered desirable, as before, to indicate a continuous slope, although the basin may partake in some degree of the nature of a graben.

(ii) *Development of the Basins*

In north-western England the great thicknesses of the subdivisions in the basins result in a paucity of thickness measurements from boreholes, for even deep borings normally penetrate only one or two formation boundaries. The figures for the Permian (Manchester marls plus Collyhurst sandstone) in west Lancashire are plotted on the accompanying map (Fig. 8); they show the great expansion from the margins of the basin towards the west. There are indications of a comparable thickening into the Cheshire Basin (although thicknesses vary very irregularly in the neighbourhood of faults), but the deepest boreholes in the central part only just penetrate the Keuper, and the extent of the expansion can only be guessed.

The Bunter behaves similarly. On the edges of the exposed coal-field the Lower Mottled sandstone is as little as 250 feet (at Parr), but it expands to 948 feet at Heswall and possibly more than 1200 feet at Ellesmere. The Pebble Beds measure 237 feet at Golbourne, and increase to 522 feet at Heswall and 1396 feet at Bidston. At Formby and Scarisbrick the Bunter totals 2020 feet and 2035 feet respectively. The Keuper sandstone is absent in the Preston district (Penwortham), it is too thin to be mapped north of Ormskirk, but it measures 970 feet at Formby and 472 feet at Marston in the Cheshire Basin.

In the Furness area the effect of faulting has been to cause encroachment of the Palaeozoic massifs on the basin area, so that the isopach lines run obliquely against the present margin of the basin when traced northwards from the Formby neighbourhood.

(c) **The Midlands**

(i) *General Structure*

The north Midland area shows a series of shallow troughs separating the outcropping pre-Permian rocks of the Coalfields. These are on a considerably smaller scale than the basins in other parts of the country, and the north-south synclines represent relatively small depressed belts on what is essentially the north-western part of the London Platform. Only in the south-west does a depression—the Severn Valley Basin—approach in size the major basins of the north.

Across the southern end of the Pennines lies the Stafford-Needwood syncline. In its centre the Chartley Chase borehole proved an incomplete sequence of more than 2000 feet of Trias, and the full thickness may approach 2500 feet. The axis of the syncline presumably runs nearly east-west, through the Needwood Forest Rhaetic outcrops and the Keuper salt-bearing beds near Stafford.

The narrow depressions which flank the south Staffordshire and Warwickshire coalfields vary from about 500 to as much as 1000 feet in depth. Steep slopes of the sub-Triassic floor appear to be exceptional, and the area is one of gentle folding and faulting.

The south Staffordshire coalfield appears to belong essentially to the Welsh Border region from the aspect of Mesozoic structure, whereas the Warwickshire and Charnwood pre-Triassic rocks form a prolongation of the shallower part of the London Platform. The Warwickshire Cambrian fold is aligned with the shallow pre-Permian of Calvert and Bletchley (Davies and Pringle 1913); the Charnwood line is continued by the shallow floor and outcropping pre-Cambrian of Sapcote and Croft towards the Oxendon and Orton borings. The syncline separating these raised areas is so shallow that they may well be regarded as fundamentally a single structure, as Fearnside showed, although they behaved as separate anticlines during Jurassic and Cretaceous times (Rastall 1925, p. 213, Arkell 1933, p. 79). The structure as a whole forms the Mesozoic southward continuation of the Pennine uplift.

It is likely that the surface of the London Platform to the south is more irregular than the isolated boring records suggest, but it is improbable that inequalities are as great as 500 feet in height. The region thus appears as a remarkably flat-topped area of shallow ancient rocks, over which were no transgressions associated with major downwarping. The Lias of western Northamptonshire, and the Oxford Clay, are the only pre-Cretaceous formations which approach their normal thicknesses over the rigid mass, and they both fail in turn towards the south-east.

The Severn Basin, which forms the south-western part of the Midland area, is bounded on the west by the Malverns, where the Keuper appears to have a partly faulted contact with the older rocks. Various borings have shown the thickness of the Mesozoic beds; thus at Newent an incomplete thickness of 1190 feet of Bunter was proved and at Upton-on-Severn Keuper measured more than 1700 feet. Keuper and Bunter are therefore likely to total some 3000 feet a little east of the Malverns, but relatively rapid eastward attenuation must take place. The structure here, a deep basin, associated with a boundary fault and—or—a scarp, contrasts with the shallow troughs of the north Midland area, and is more closely analogous to the structural type of the north-western basins.

(ii) *Development of the Midlands Synclines*

In the east-west Mid-Staffordshire syncline there is a clearly marked thickening of the Trias (with Bunter and Lower Keuper) from the northern edge and also, in some places at least, from the southern margin towards the centre. The alinement of this trough with the east-west Old Dalby-Waltham syncline of north Leicestershire, farther east beyond the Charnwood nose (Kent 1937), suggests a likelihood of progressive development during Jurassic times.

The nearly north-south synclines present a contrast. Wills (1935, Fig. 31) has indicated that the north-south troughs separating the south Staffordshire, Warwickshire and Leicestershire coalfields had no independent existence during Keuper and Bunter times, but that the Trias thickens progressively from Northamptonshire westwards into Shropshire. The development of the individual downwarps is ascribed to "very gentle flexuring accompanied or followed by profound faulting," probably in mid-Tertiary times (*ibid.*, p. 242).

Arkell, on the other hand, has suggested that the outcrops of pre-Permian rocks are on the lines of prolongation of the south Midlands Jurassic "axes" and could be expected to have had similar, if not more pronounced, histories of intermittent long-continuing uplift. Comparison might therefore be made with the Market Weighton area, where a Jurassic uplift developed in a Permo-Triassic syncline. One cannot, however, exclude the possibility that the Jurassic axes of the south Midlands are dying out northwards instead of southwards, and that little warping of the coalfield areas took place before the close of the Cretaceous.

In the south Midlands the Severn Valley trough has clearly developed progressively during Mesozoic times. The fact is sufficiently illustrated by contrasting Buckinghamshire, where the Trias is absent, with Worcestershire, where the great thickness of Keuper and Bunter indicates a differential movement measured in thousands of feet. The relation of the Malverns to the downward movement is, however, far from clear; the evidence of faulting does not necessarily suggest a major fracture, and it is perhaps equally probable that the edge of the Triassic basin lay near the Malvern line.

(d) **Southern England**

(i) *General Structure*

South of the Thames the depth of the Palaeozoic rocks has in the past been the subject of various widely varying estimates. In particular the Mendip anticline was for long assumed to continue through Kingsclere and Guildford as a high standing ridge with Jurassic formations thin or absent over it, and the South Downs were thought to overlies the edge of a stable block similar to the massifs beneath London. The Portsdown, Henfield and Kingsclere borings

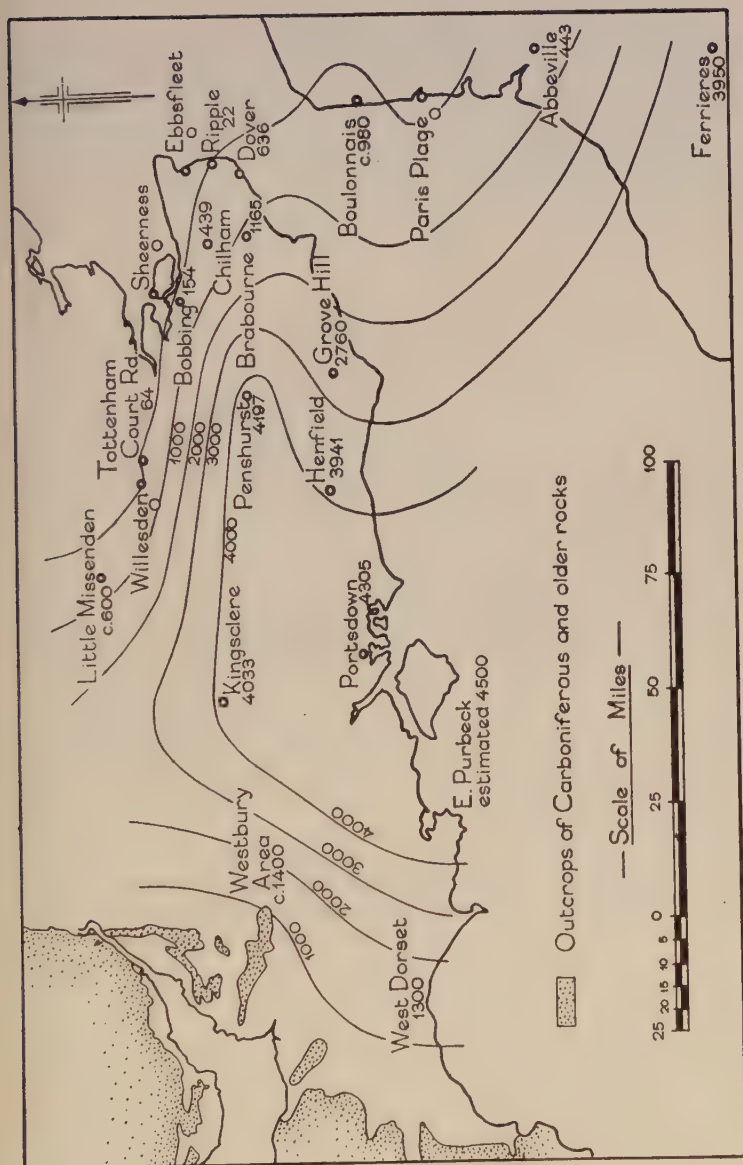


FIG. 9.—THICKNESS OF JURASSIC ROCKS IN SOUTH ENGLAND AND THE CHANNEL COASTS.
The Rhaetic is included in the Jurassic.

have greatly modified these ideas, and shown the area to be a single large depositional basin (Fig. 9).

Portsdown is the deepest part of the basin so far proved. The Keuper was reached at 6300 feet below sea level in the deep boring there, and it has been assumed in drawing the map that Palaeozoic rocks lie at about 8000 feet below sea level; the basement could, however, be 1000 feet or more deeper than that figure. The Solent syncline immediately south is probably more than 3000 feet deeper than the Portsdown culmination, and the Palaeozoic surface is therefore possibly there in the neighbourhood of 12,000 feet below sea level.

At Kingsclere Keuper with Carboniferous pebbles was drilled from 4523 to 4588 feet below sea level, and the pre-Permian rocks are assumed to lie little deeper, having regard to the thinness of Trias in the areas to the north-east and west.

In the centre of the Weald the Penshurst boring proved the Palaeozoic surface to be much deeper than at Grove Hill (Hellingly) to the south, and nearly as deep as at Henfield. Certain possible Permian deposits at Henfield and Grove Hill are too thin to affect structural conclusions, and they have been included with the Carboniferous and older rocks on the present map. A thinning of the Jurassic rocks with a rise in the Palaeozoic surface in the region of the South Downs is therefore established, but it is a much smaller feature than that postulated by Lamplugh and, although it is of considerable importance, it is not comparable with the London-Brabant Platform.

It may be observed in passing that the deep borings have finally negatived the somewhat ill-founded suggestion that the Wealden structure is due to tectonic thickening of the Mesozoic strata, for the beds at depth prove to be no more disturbed in the Weald than they are over the London Platform.

In accordance with the indications provided by our drilling results, the sharp folds of the region have been taken as entirely post-Cretaceous, neglecting the partly known but probably relatively small Lower Cretaceous movements; their amplitude has been based on an unpublished Structural Contour map of the Middle Chalk by F. D. S. Richardson (1935). In Dorset a one-inch-to-one-mile contour map of the Corallian surface (using recent shallow drilling data) was drawn as the basis for the present map.

The Mendip area appears as a shelf-like projection from the Welsh Highland, and the thin development of Jurassic rocks may be regarded as a shoreline condition—an extension of the littoral region of Glamorgan. The accident that the outcrop crosses this submerged peninsula, taken with somewhat insecurely founded assumptions on the nature and persistence of axes of uplift, led to the belief

that a Mendip anticlinal axis, forming a more or less complete barrier, persisted across most of southern England during much of Jurassic times, despite long recognition that the facies of Lias and Oolites at Dundry Hill near Bristol belong to the southern province.¹ The Kingsclere results show that the fold plunged towards the basin, and that there was free connection from north to south in deeper water, where deposition was only rarely interrupted.

The structural contour map agrees with stratigraphical evidence in indicating that west Kent, Sussex, Hampshire, Wiltshire and Dorset are underlain by a single depositional basin. This goes so far beyond the bounds of Hampshire that the name Hampshire Basin is inappropriate (other, of course, than for the Tertiary syncline), and the name Wessex Basin is suggested for the larger feature.

In south Dorset and the Isle of Wight the depth to the pre-Permian floor has been estimated from the expected thickness of Jurassic rocks, with the assumption, which seems reasonable, that in the south of the Isle of Wight thicknesses are much the same as in east Dorset. The thickness of the Permo-Trias remains subject to speculation, and forms an additional uncertainty in the calculation, but the explanation of the south Dorset structures as due to salt tectonics leads to the possibility that it may be considerable in this region (Lees and Cox 1937, p. 174).

From the area of shallower Palaeozoic rocks of south-east Sussex the contours must swing generally south-eastwards towards the trough of the lower Seine region. The Sussex coast thus overlies a structural nose which separates the eastern end of the Wessex Basin from the syncline beneath the English Channel, a continuation of the Paris Plage ridge which separates the Jurassic syncline of the Boulonnais from that of the Pays de Bray (Pruvost 1930). Farther west the asymmetrical anticlines of the Isle of Wight and Dorset are somewhat similarly situated on a slightly different line, with the basin to the south indicated by the southward dipping beds of Ventnor and Portland. The movement of this fold appears to be mainly Cretaceous and later (Wooldridge and Linton 1937) in contrast with the Jurassic movement of the stable area under the Sussex coast.

The Wessex Basin may be regarded as a northern extension of the Paris Basin itself, for the English Channel overlies the north-western part of the latter (Lemoine 1930 ; Van der Gracht 1938). The broad folds which follow the south coast of England did not provide any continuously separating ridges, for although the Jurassic and Cretaceous rocks thin towards this belt, all subdivisions remain well developed.

(ii) *Development of the Basin*

In the Wessex Basin the evidence of progressive development throughout the Jurassic period is amply clear, and may be illustrated

¹ The occurrence of occasional members of the Cotswold Jurassic fauna in the deep wells at Portsdown and Henfield provides additional palaeontological evidence of the connection.

in the northern part by figures along a line running from the Mendips across the trough to the margin of the "London Platform."

	Mendips	Westbury	Vale of Pewsey	Kingsclere	Shillingford	Calvert
Purbeck				540	0	
Portland			c. 45	155	0	
Kimeridge			c. 450	921	112	
Corallian			80-116	172	79	
Oxford Clay		600		348		
Gt. Oolite Series	140	318		275		105
Inferior Oolite	0-44	128		359		0
Lias	0-200			1186		241

Thicknesses are given in feet

Near the south coast the westernmost part of the basin underwent deep erosion before deposition of the Upper Greensand, but in the eastern marginal area the Jurassic beds remain beneath the Cretaceous, and the evidence of expansion towards the deeper part is again seen in each subdivision.

	W. Dorset	W. Purbeck	E. Purbeck	Portsdown	Henfield	Elham	Bere Farm
Wealden	0	750	2300	785	920+	153	42
Purbeck	0	176	400	250	520	0	0
Portland	0	150	230	81	98	0	0
Kimeridge	0	750	1650	1102	1082	199	0
Corallian	0	250	c. 600 ¹	142	299	207	57
Oxford Clay	0	500 ?	-	442	561	154	126
Gt. Oolite Series	410	-	-	465	338	167	95
Inf. Oolite & U. Lias	140	-	-	669	572	49	0
M. & L. Lias	750	-	-	1088	500	58	0

Thicknesses are given in feet

The moderate attenuation of many subdivisions at Portsdown may reflect either early movement of the Portsdown anticline, which, however, does not make itself evident in the development of non-sequences, or regional thinning on the line of the Artois-South Downs *schwelle*. If the latter were the case it would mean that the Dorset coast folding is not connected with this general structural line, but is en echelon with it.

¹ Assuming the lower Corallian to be expanded in the same proportion as the upper part.

III. CONCLUDING NOTES

It is interesting to notice that the major Mesozoic basins are not, in general, closely related to Palaeozoic synclines.

In the north-west, for example, the margins of the west Lancashire Basin cut at a high angle the tectonic lines of the Carboniferous rocks. In the Cheshire Basin the Mesozoic rocks have the appearance of breaking in on the northern margin of St. George's Land, whilst the deepest part lies well south of the deepest part of the Carboniferous trough and coincides with a structural rise in the Carboniferous rocks. In north-eastern England the independence of intra-Carboniferous and Permo-Mesozoic sedimentation is illustrated by the fact that these formations are thinning in opposite directions (the Carboniferous to the east, the later beds to the west), and by the essential absence of change in the later rocks in crossing the Craven fault system. The relation of the Permo-Mesozoic rocks to Variscan folding is illustrated by the lack of any large scale effect on the former where important folds are truncated, and by the maintenance of thicknesses where, for example, the later rocks transgress from Coal Measures on to Lower Carboniferous in Yorkshire.

The example of closest congruence of late Palaeozoic structures and major Mesozoic basins is perhaps provided by the northern edge of the Mesozoic London Platform (Brabant Massif) which nearly coincides with the northern limit of the Carboniferous "St. George's Land." In detail there are numerous discrepancies in the boundaries of the two structures, but they may nevertheless be due to essentially the same fundamental cause.

It seems reasonable to conclude that Permian and Mesozoic structures *on the scale of the major basins* (fifty miles or more across) do not arise from posthumous folding, but are due to vertical movements on essentially different lines from those which controlled pre-Permian sedimentation. The relationship of smaller Mesozoic structures to the Palaeozoic Platform is a somewhat different question, and it is hoped to discuss new data bearing on this at a later date.

A further important point emerging from the review is that there is clear and unmistakable evidence that the separate basins are essentially Permian and Mesozoic features and do not owe their positions to Tertiary movements—although the latter have of course produced modifications in detail. This confirms the arguments put forward by Arkell (1933, pp. 567-99) before data from the recent series of deep borings were available.

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DISCUSSION

PROFESSOR HOLLINGWORTH expressed his appreciation of the vast amount of work which had gone into the preparation of the author's paper and of the map exhibited on the screen. He enquired as to how far it was practicable to distinguish the various factors that had contributed towards the development of the form of the Sub-Permian surface as portrayed by the author. In the North-Eastern Basin the author referred to the wave-cut platform, but there appeared to be some evidence of an irregular floor to the Permian deposits in the Tees area, and the conception of a wave-cut platform rather suggested a progressively transgressive sea in early Permian times. In other words the pre-Permian surface might have had an original slope.

West of the Pennines the restricted extent of the 2000-ft. thick Penrith Sandstone, predominantly aeolian in origin, and interbedded with thick marginal Brockrams, was strongly suggestive of the infilling of a pre-existing hollow. Similar conditions were, of course, characteristic of much of the Midland Basin of deposition in Triassic times. The author had appreciated the importance of differential downwarping during the deposition of the Permo-Triassic strata. We had therefore three distinct features contributing to the author's structure contour map :—

- (a) The Pre-Permian topography.
- (b) The Permo-Triassic downwarping.
- (c) The Post-Triassic deformation.

In any consideration of the distribution and character of the evaporites of the Permo-Trias it was important to distinguish as far as possible between these three factors since it appeared that the second factor exercised a dominant influence on the nature of these precipitates. The speaker enquired as to how far it was possible to assess the individual influence of the three factors.

A particularly important aspect of the author's results was the demonstration that much of the Permian and Post-Permian movements was independent of the earlier structural trend lines. Professor Hollingworth expressed his congratulations to Dr. Kent on the completion of a most valuable work.

PROFESSOR KING wished to congratulate Dr. Kent on the publication of this extremely interesting map. A synthesis such as this will prove to be of the greatest value and a basis for much further work and speculation. He hoped it would be possible to prepare maps of the pre-Permian surface as it was (a) before the Permian sediments had been laid upon it, and (b) at various subsequent dates such as the end of the Trias, at the end of the Cretaceous and the end of the Miocene. These maps would show the position and depth of the "western

basins" at various geological epochs. It may then be seen that these basins are responsible for much of the existing topography of western Britain and that this topography is due to the excavation of the soft sediments from the Permo-Trias filled basins giving rise to the hollows (either sea-filled or lowlands) which mark the present topography.

DR. J. F. KIRKALDY, whilst fully appreciative of the importance of the contoured map presented and the amount of work that it involved, felt that its value would have increased, if some indication had been given as to the relative reliability of the contours in different areas. Where borings were closely spaced, and perhaps other evidence was available, there could be little question as to the reality of the minor sinuosities in the contour lines. In other areas, notably in parts of S. England, with fixed points few and far between, the contours could give only the broad picture and minor sinuosities must be based on inference and not really on fact. Doubtless the quality of the evidence was dealt with in the text, but the map, when published, would come under close scrutiny and the presence or absence of minor bends in the contour lines, at, for example, the various "axes of uplift" affecting the Mesozoic beds, would be of interest to many people. It therefore seemed rather unfortunate to the speaker that no indication of relative accuracy had been given on the very valuable and instructive map shown at the meeting.

MR. RICHARDSON thanked the members for their kind reception of Dr. Kent's paper, and welcomed the stimulating comments which had been made.

The view that the sub-Permian surface in the North-Eastern Basin was predominantly a wave-cut platform was prompted by the remarkable evenness of slope indicated by borings in and east of the Yorkshire-Nottinghamshire coalfield and in the Durham coalfield; the speaker agreed that this surface must have had an original slope, however gentle. The influence of the various factors affecting the form of the surface and the nature of the precipitates in the several basins had not yet been systematically assessed. It was hoped that Dr. Kent would eventually undertake this task and would also prepare a series of maps illustrating the development of the basins and their influence on the present topography. In conclusion, the map shown at the meeting was a simplified version from which the bore-hole evidence was omitted; this evidence would, however, be shown on the published map.

THE HISTORY OF THE RIVER DART, DEVON

By J. F. N. GREEN

[Received 16th November, 1948]

SUMMARY

The river Dart is about 30 miles long with a fall of 1800 feet. The pattern of its drainage on Dartmoor, omitting portions controlled by jointing, is explained by a scarp-land, originating in Lower Oligocene time on a marine plain sloping east, subsequently tilted southwards.

Evidence is given for a river terrace graded to 1150 feet, and for the 1000-foot and 800-foot terraces of Barrow with an intermediate 920-feet. The sea then occupied a gulf near Holne. The shore shifted to the vicinity of Teignmouth and terraces graded to about 690, 595, 505 and 430 feet were formed. The great diversion southward took place in the 430-foot period. During the Sicilian, Upper Ambersham and Ambersham terraces, the river flowed by Brixham. Later terraces followed the latest diversion to Dartmouth. A terrace along an ancient valley is ascribed to the effect of beheading.

The Dart valley above 1500 feet shows signs of glaciation. The relation of eyots to nicks is considered. Finally the question of subaerial versus marine planation is discussed and old sea-levels compared with those of the Mediterranean.

MOST of this work on the river Dart was done before the war. It was hoped that a full survey could be made of the profile and the associated terraces, but war conditions stopped nearly all mapping until the summer of 1947. Circumstances then made it impracticable to do more than fill in some gaps. Therefore the writer is almost wholly dependent on map indications for details above 1300 feet O.D. Fortunately a long series of spot-levels on the alluvium of both the East and West Dart enable fairly satisfactory profiles of the upper courses of these streams to be constructed.

There are other sources of error. Many of the heights are by aneroid; and in the important section of the profile between New Bridge, 320 feet O.D., and Dartmeet, 740 feet O.D., nothing else is available. Most of the river gravels have been worked over by tinnors, so that the levels of the flood-plains have to be inferred, either from the large boulders left untouched, or from an assumed thickness of gravel above the rock-lip. Many undetected fragments of terraces must exist in the more wooded and steeper parts of the district. The writer had to rely on his results in east Devon [1]* for sea-levels between 400 and 600 feet O.D.

It is, however, hoped that the ascertained facts are of sufficient interest, especially in their bearing on general theories of landscape evolution, to lead others to test, correct and extend them.

The Origin of the Drainage Pattern.—The Dart is a small river, only about 30 miles long measured along the thalweg from tide-head, to which must be added some 10 miles for the drowned

* For list of References, see p. 123.

estuary. It is very steep, falling over 1800 feet and, draining one of the wettest districts in England, is rapid, violent and often dangerous. According to R. H. Worth [2] the volume in flood may be 3900 times as great as summer normal.

The pattern of Dartmoor is peculiar. It has been said to radiate, because the principal rivers all start near Cranmore Pool in the north-west. But, though there is a peripheral drainage round the granite elevation, there is little evidence for a radiate drainage, past or present.



FIG. 10.—MAP OF THE RIVER DART AND NEIGHBOURHOOD.

The minor streams tend to follow the jointing, which, over much of the granite, is roughly north-west-south-east and north-east-south-west. Parts of the main streams are also controlled by this structure. The more important in the Dart basin on Dartmoor are, from west to east :—

A mile and a half of the Blackbrook river near Princetown, which runs south-east.

The Strane-Swincombe rivers, the principal southern tributary.

These follow closely the directions of the leading veins of the Whiteworks mines, situated at their junction.

The upper part of the O Brook, which follows the directions of the veins near it.

The only northern tributary much affected is the East Dart, which, from the neighbourhood of Cut Hill to about a mile north of Dartmeet, has six miles flowing in a direction 35 degrees east of south, that is, perpendicular to the main veins of the mining belt of Birch Tor. The six miles are broken by two mile-long reaches flowing south. The mining belt, three miles long, begins a mile and a half north-east of the East Dart, and is followed by a series of drainage lines also perpendicular to it, of which the most striking is that of the river Bovey (see map, Fig. 10).

The river Yeo developed independently, later than the main drainage of the granite to the Dart (p. 118).

Apart from the portions mentioned above, the Dart drainage system forms a consistent pattern not controlled by the internal structure of the solid rocks.

In 1904 Jukes Browne [3, p. 333] inferred that the streams from Dartmoor probably ran eastward at first and suspected that the Dart originally passed along the present Teign estuary. The Pliocene channel of this ancient Dart has since been described by the Geological Survey [4].

The pattern of the early river resolves itself into a trunk flowing eastward, the average direction, at the end of Pliocene time, from Princetown to Bickington, being six degrees south of east; and a series of tributaries joining the trunk's north bank with predominantly southward courses. From east to west these are East Webburn; a dissected valley, drained to the West Webburn; the West Webburn, joining the East Webburn; parts of the East Dart; the Walla Brook, joining the East Dart; the Cherry Brook; the upper West Dart; the Cowsic river; the headwaters of the Blackbrook. To these should be added the headwaters of the Walkham river, formerly continuous with the upper Blackbrook, and part of the main Walkham river, which beheads a former extension of the trunk along and west of the lower Blackbrook. The river Meavy is now not far, geologically, from beheading again at Princetown.

The only fragments of tributaries flowing north to the trunk are the terminations of the Swincombe river and the O Brook, each about a mile. The Moor south of the Dart basin is chiefly drained by the south-flowing Avon, Erme and Yealm, and by the Plym on a course of south- and west-flowing zigzags. There is some evidence that parts of these streams were at one time tributaries of an east-flowing river, of which relics remain as the lower Harbourne, and the valley marking the Ambersham course of the Dart to Brixham (Fig. 10).

Thus the pattern on Dartmoor of the Dart basin is that of "scarpland topography" developed on a sedimentary series dipping east, but with north-flowing subsequents suppressed. This may be inferred to have originated on a plain with an easterly slope. Imposition of a southerly slope would strengthen south-flowing subsequents and weaken those flowing north and would thus account for the peculiarities of the Dartmoor pattern.

The shape of Dartmoor is not dome-like. Since denudation is controlled by gravity, no appreciable error will result from not treating the area as spheroidal, and it is then easy, using co-ordinates measured on the one-inch maps, to fit a plane surface closely to six principal heights, Hangingstone Hill, 1984 feet; Cut Hill, 1981; Hameldown, 1737; Hameldown Beacon, 1697; Ryder Hill, 1682, and Rippon Tor, 1564. This plane passes about 60 feet above the highest point of the Moor, High Willhayes, 2039, and above Petre's Cross, 1575, the dominating point of the south. It is not surpassed by any Moorland height. It slopes about 30 degrees south of east at one in 130, and could be produced from a plane sloping east at one in 160 by a superimposed slope south of one in 260.

A plain can be suggested from which such a surface as that of Dartmoor could be made by denudation. The sarsens and pudding-stones of east Devon [1, p. 46] are known to within 12 miles of the granite, as at present exposed, and show that little but Cretaceous rocks were being eroded in that neighbourhood. This supports the inference from the work of A. W. Groves on the distribution of Dartmoor detritus [5], which indicates that the metamorphosed area was vigorously attacked in Upper Cretaceous time, but was not much, if at all, exposed during the Eocene. The supposed Eocene gravels of Haldon, which contain Dartmoor detritus, are, in the writer's opinion, actually not older than late Miocene [1, p. 46. See 23]. The Bovey Beds show that the granite was being eroded in the Middle Oligocene. It is therefore probable that Dartmoor was planed off by the sea when the basal Eocene was deposited and that it became land in Lower Oligocene time as a Palaeozoic foundation with a cover of Cretaceous and Eocene sediments. Assuming an easterly slope, all requisites would be present for construction of a scarpland with consequents flowing east and subsequents flowing north and south. By the Middle Oligocene the rivers were down to the granite and carrying its waste into the Bovey depression. It would seem that at the same time folding was tilting Dartmoor southwards, extending the south-flowing subsequents and killing those flowing north.

This explanation is fundamentally that given by Jukes Browne, though arrived at by a different line of reasoning. He wrote [3, pp. 323, 325]:

"We may reasonably conclude that it was at the beginning of Oligocene time that the present river system of Devonshire was initiated" and

"The courses of the rivers of southern England seem to indicate the influence of two slopes . . . the one slope was easterly and the other was southerly ; the latter is now the dominant slope, and consequently I think that it is of later date than the other."

The 1150 feet Terrace.—The post-Oligocene history is written in the terraces, though the earliest have not yet been deciphered. Research actually began with the later and better preserved terraces, but exposition is clearer if starting from the higher and older landscape.

For reasons given later (p. 120) the river profiles above 1500 feet O.D. have not yet been of assistance. The first definite information is in the West Dart (Fig. 11), where eight Survey spot-levels from 1504 feet to 1397 feet along two-thirds of a mile yield a logarithmic

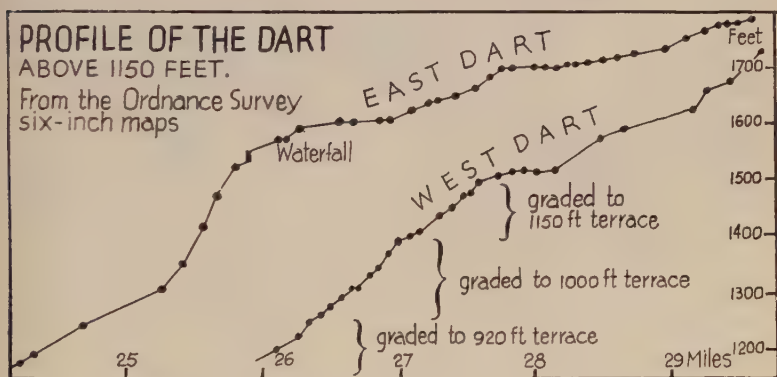


FIG. 11.—PROFILE OF THE DART above 1150 feet.

curve which extrapolates to 1280 feet at Two Bridges. Three Survey levels from 1463 to 1373 feet on the Cowsic river are also graded to about 1280 feet at Two Bridges. This level is represented by a terrace at 1300 feet above the Blackbrook river half a mile south-west of Two Bridges. North of Huccaby a considerable area slopes gently upwards from about 1200 feet. The curve then comes to a remarkable flat on which stands Combestone Tor. It all lies approximately between 1165 and 1150 feet, including the tor. A mile to the east a larger flat is mostly 1115-1120 feet, but rises to 1150 feet at the south end.

There seems to be an ancient shore-line as marked in Fig. 12. Whether this is the head of a gulf or not is uncertain without further information, but the position of the later shores and the slight slope of the calculated curve suggest that a coast was in the vicinity. This sea-level would represent the 1150-feet maximum found in Hollingworth's diagrams for this and other areas [6].

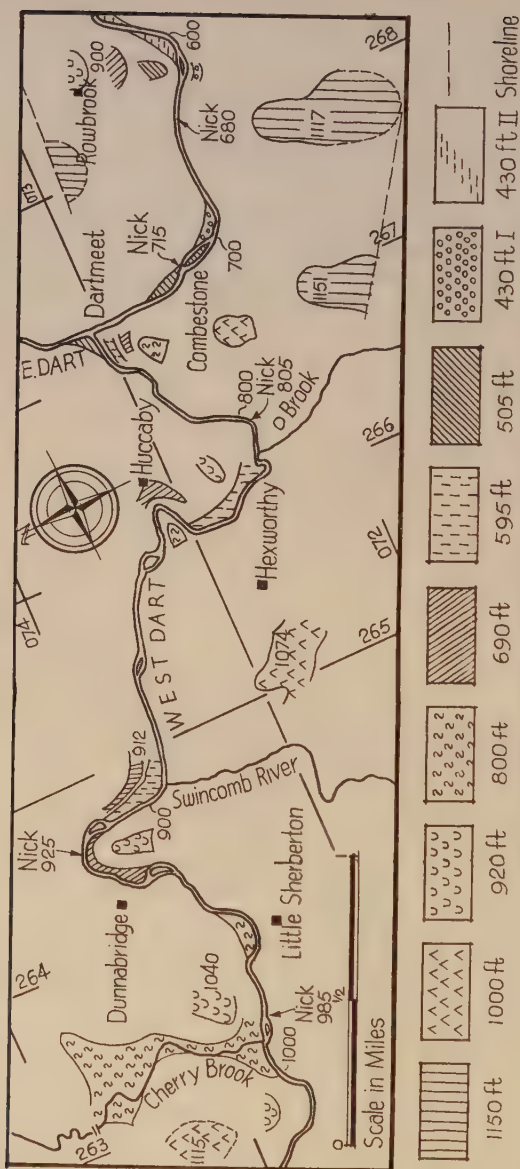


FIG. 12.—THE VALLEY OF THE DART NEAR HEXWORTHY.

The 1000-feet, 920-feet and 800-feet Platforms.—Three shore lines, equivalent to Barrow's 1000-feet and 800-feet platforms, with an intermediate 920-feet, have been mapped in the Holne district. The 1000-feet, the upper limit of which is usually about 1040 feet O.D., is described by the Survey [4, p. 68]. It is a striking element of the landscape and the ancient line of cliff can be determined without difficulty (Fig. 13). The 920-feet platform is seen at Middle Stoke, south of the river, and at Aish Tor, north of it. The coast line here must have run about a quarter of a mile from that of the 1000-feet. The platform appears also to be present in Ausewell Wood, near the 1000-feet coast, but, as the wood is still a danger area, could not be measured. North of Ausewell there is a fine development of a platform sloping from 820-825 feet to 760 feet. It has been mapped for half a mile. Much of the western part is concealed by an old overgrown scree of great boulders. This is Barrow's 800-feet platform and Balchin's 820-feet shore [7, see also 1, p. 47].

The nicks on the West Dart corresponding to the 1000-feet coast are at about 1390 and 1270 feet. Seven intervening Survey levels are available. They lead to a small flat north-east of Two Bridges at 1220 feet and to a large one half-way to Cherrybrook from 1150 to 1115 feet. A terrace averaging 1080 feet lies above Hexworthy; near Dartmeet it recurs at 1050 feet (Fig. 12).

The flood-plain of the 920-feet terrace has four Survey levels from 1267 to 1196 and is fixed by a benchmark as about 1105 feet at Two Bridges. The lower nick appears to be complex, extending from half a mile below Two Bridges to near the Blackbrook junction at an average height of 1050 feet, but has been so disturbed by tinning that the beginnings of the elevated terrace are obscure. It is 10-15 feet above the river at the junction. Fragments as shown on Fig. 12 carry on till near the 920-feet level at Rowbrook.

The position of the lower nick of the 800-feet terrace is doubtful, but it is believed to be complex, extending from a little below Cherrybrook at 985 feet O.D. to eyots south of Dunnabridge at about 950, which have not been visited. Fragments of the elevated terrace are noted at Huccaby, Dartmeet and Rowbrook. Below Aish Tor (Fig. 13) a small terrace has its lower edge at the 800-feet contour, the upper part being overwhelmed by old scree. Its orientation suggests a river-terrace rather than a shore, so the actual mouth may have been about a mile to the east.

Throughout this research the identification of terraces has been greatly assisted by the use of logarithmic curves. In general, however, the levels of the flood-plain have not been numerous and accurate enough to test the fit. In the case of the Taplow terrace (Fig. 16), where frequent levels are available, a simple logarithmic curve is adequate, and the same can be said of all measured terraces originating in the Pleistocene of other rivers. But the Survey

levels on the West Dart show that the flood-plains of the 1000-feet and 920-feet terraces are too strongly curved to allow of more than short extrapolation. This should have been expected from the diminution of volume as backward erosion ascended the streams, and equivalent decrease in the parameter. It can be compensated by using the full form of the equation found by O. T. Jones [8, p. 589]. The 920-feet terrace is well given by

$$y=1121-175 \log (160 x)+1.1 x$$

where x is measured in sixths of a mile from Totnes railway bridge.

The 690-feet Terrace.—There is no further sign of a shoreline west of Ashburton. The next that can be identified is near Teignmouth. About two miles north-west of the town the ground drops sharply from the summit of Little Haldon to the 700-feet contour from which a spur is given off eastward, which descends with slight undulation to 650 feet in just under a mile. This appears to be a relic of the platform at this height now known over much of southern England and mapped in east Devon as the 690-feet platform. The shoreline seems to have been almost parallel to the present coast.

Taking the corresponding upper nick to be the lower nick of the 800-feet terrace, the flood-plain would end half a mile downstream, east of Dunnabridge, at 925 feet (Fig. 12). An elevated terrace has been mapped nearly half a mile downstream, being 10 feet above the flood-plain opposite the mouth of the Swincombe river. It is noted again at Huccaby Church, Dartmeet, Rowbrook and Middle Stoke. It is next seen clearly six miles east on Ashburton Down near the 750-feet contour. So wide a gap makes connection somewhat doubtful, but there are indications which help to fill the hiatus. A survey station at 773 feet O.D. on Green Down (Fig. 13) seems to be on a slightly eroded platform, and there is a strong terrace on the East Webburn, described by the Survey [4, p. 66], which, according to the writer's measurements, would extrapolate to the junction with the Dart at about 765 feet.

Nothing more can be seen till two miles west of Teignmouth, where a spur of Haldon runs south-west for a quarter of a mile, a little above 700 feet.

Thus there must have been a great change in the coastline between the formation of the 800-feet and 690-feet platforms; that is, if the attribution of the latter to Diestian time is sound, between Miocene and Pliocene time. While the extent of this change can only be settled by further research, it is probable that a gulf or deep followed an east-to-west syncline responsible for the embayment of the sedimentaries round Holne in the granite, and that this Miocene gulf became land with the oncoming of the Pliocene. At this time, too, the Yeo, which had begun as an insignificant peripheral brook, became a tributary of the Dart.

The 595-foot Terrace.—The Dart is well graded from the nick at 925 feet east of Dunnabridge to a point near the junction with the O Brook, where there is a strong change of slope at about 805 feet. The emergence of an elevated terrace there has not been verified, but one is seen at Dartmeet, perhaps 20 feet above the flood-plain. But the gravels are so disturbed that accurate estimation is impossible.

A curve adjusted to the flood-plain and the Dartmeet terrace points to a marked flat at Gallant Le Bower, 685 feet (Fig. 13), and continues to Hook's Cross, north-east of Ashburton (Fig. 14) at 650 feet. There is a small flat at 640 feet on Telegraph Hill, near Bickington, and another at 605 feet on a spur nearly two miles west of Teignmouth.

It is believed that this series belongs to the most important of the Pliocene platforms, mapped in east Devon as the "595-foot

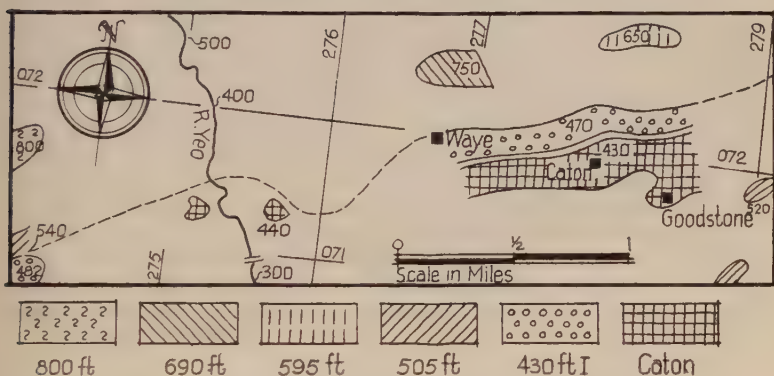


FIG. 14.—ANCIENT VALLEY OF THE DART NEAR ASHBURTON.

platform.” The evidence, however, for connection of the flood-plain with Gallant Le Bower is by no means adequate, as the gap is four miles direct with a difference in height of a hundred feet. So prolonged a standstill would account for the length of the flood-plain section, which is on the way to over-running the 690-foot section, and for the strongly marked lower nick ; but, without further confirmation the ascription must be tentative.

The 530-foot and 505-foot Terrace.—The 530-foot platform has only been separated in east Devon, whereas correlations with the 505-foot platform are known in many places in the south of England. No signs have been noted of any separation in the present river, and it has been assumed that only the lower and larger of the two is to be seen.

The Dart is well graded from the 805-foot nick to Combestone Island, half a mile south of Dartmeet. At this point an elevated

terrace is given off, which, south of Rowbrook, is at the 700-foot contour. It can be followed through Fig. 13 at Holne, Kinghurst, Staddicombe, and finally Druid at 540 feet. East of Ashburton it was noted near Goodstone (Fig. 14) as flat-topped hills, estimated at 520 feet. A mile east of Bickington a spur runs from 520 to slightly below 500 feet.

The 430-foot Terraces.—The flood-plain below Combestone Island develops half a mile downstream an elevated terrace which, opposite Rowbrook, is much covered by scree, but seems to be about 650 feet. North-west of Hannaford (Fig. 13) a fine flat has its lower edge 605 feet. From this a series of flats lead to one at 490 feet, north of Staddicombe. The river then turned north-eastwards across the present line of the Dart, here flowing south to Druid Cross, where a terrace bears a spot-level 482.

The ancient valley of the Dart can be mapped with considerable accuracy from this point, a mile north-west of Ashburton, as far as Highweek near Newton Abbot, a direct distance of seven miles. The old floor is especially well preserved at Goodstone, two miles beyond Ashburton (Fig. 14), where it is 600 yards across in two tiers, and, between, a bluff 15 feet high. Both tiers are well seen at Caton, where the upper tier slopes inward from 480 to 462 feet O.D. The main terrace grades from Druid Cross to the upper floor. Further measurements are lacking for five miles eastward, but a curve adjusted to those mentioned touches the lower part of a flat three miles north-north-east of Newton Abbot, which slopes from about 420 to below 390 feet O.D. This belonged rather to a predecessor of the Teign, then a tributary of the old Dart; it is taken to be part of a horizontal segment of the 430-foot terrace. It reappears three miles west of Teignmouth.

The writer now believes that his former view that the great diversion took place in Sicilian time is wrong, and that it must be referred to 430-foot time. Measurements made since 1936 cannot be reconciled with a connection between the lower tier of the ancient channel and the Sicilian or 100-metre platform. The origin of the Caton terrace and of the peculiar course of the river Yeo will be considered later (p. 118).

Re-examination of the col at Headborough, half a mile east of Hele (Fig. 13), through which the Sicilian river was supposed to pass, shows that it is not a valley floor, but is made by double erosion in a band of soft Devonian slate. The heads of the two rivulets concerned are only 150 yards apart. It is best, too, to drop the term "Poundsgate," as the correlation of the terrace mapped at that place by the Survey is not certain.

The next flood-plain reach, which is believed to mark the diversion, has a strongly developed nick near 560 feet. The equivalent terrace follows the line of the big meander of the Dart, now, it would seem, sharply incised and permanently established.

It crosses the 500-foot contour west of Hannaford, is at 435 feet O.D. at Hele, and is then seen at a Survey station in Shere Wood at 424 feet O.D., on the western end of a platform rising east to 430 feet. This is the first of a series of similar platforms, slightly above 400 feet, which can be followed down the modern Dart to the old channel at Brixham (Fig. 15). Ten of these have been noted.

A feature of this second 430-foot terrace is the length of the horizontal segment, of which some 16 miles is seen.

The Sicilian Terrace.—The nick next below that at 560 feet is marked by a series of eyots and rapids near 450 feet. An elevated terrace appears near it, which has been followed for nearly a mile to Hannaford. Fragments near New Bridge continue it to below 400 feet. The curve points to a terrace, nearly half a mile long,

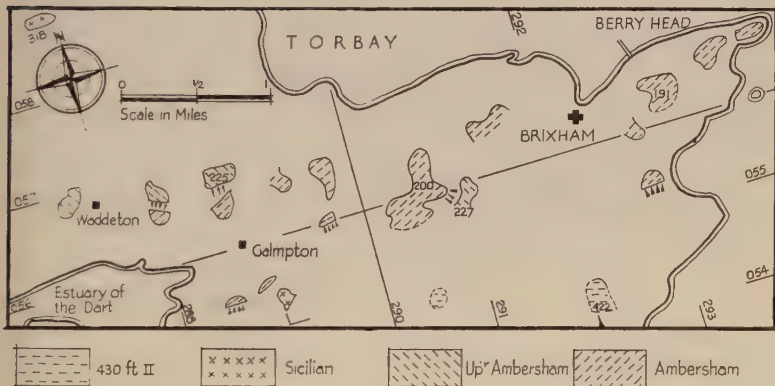


FIG. 15.—THE OLD VALLEY OF THE DART NEAR BRIXHAM.

above Home Park Cottages, at an average of 350 feet, and to a flat opposite the mouth of the Mardle, roughly measured as 345 to 330 feet O.D. South of this several fragments, usually about 320 feet, indicate a horizontal segment at least 10 miles long. This must be the 100-metre or Sicilian terrace.

The Ambersham Terraces.—There is an Upper Ambersham terrace, graded to a sea-level 25 feet above that of the Ambersham. Little has been seen of it, but it appears to have been over-run. The best evidence is near the Ambersham of the old channel to Brixham (Fig. 15), where fragments occur at 225 feet O.D. Flats assigned to it are at Moothill Cross, north of Staverton, Buckfastleigh church, 274 feet, and in Holne Park.

The Ambersham terrace is strongly developed. For over a mile, between the 400-foot and 300-foot contours, there is a broad flood-plain, in places 300 yards across. This terminates in a series

of eyots, the elevated terrace starting at the bend below New Bridge. Near the Webburn junction the Ambersham terrace is perhaps 12 feet above the flood-plain. Two miles farther downstream it is well seen near Holne Bridge, where the gravels were described by De la Beche [9]. The gravels also constitute the highest part of the complex series of gravel spreads at Summerhill Cross (see p. 117), where they are at about 265 feet. The next measurement is three miles farther down at 233 feet. Then fragments lead to a horizontal segment beginning about four miles south of Totnes.

In Ambersham times the river followed its present course till near Galmpton, when, instead of turning south, it swung eastward to Brixham. Past Galmpton the north bank fails, but parts of the

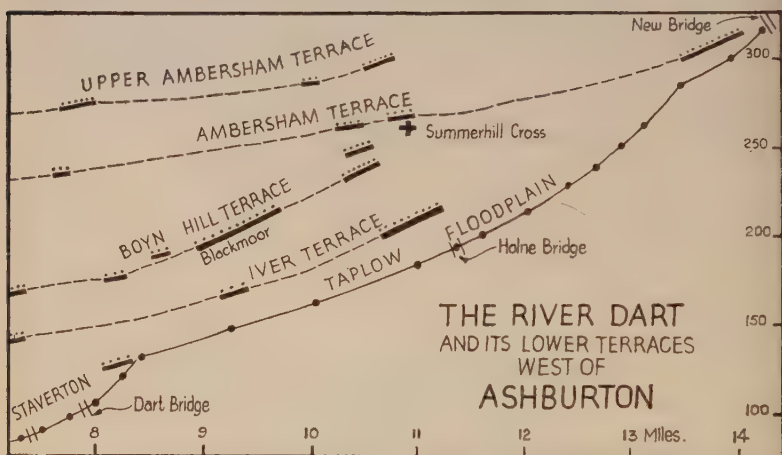


FIG. 16.—THE RIVER DART AND ITS LOWER TERRACES, west of Ashburton.

floor at 200-190 feet are common for four miles to Berry Head (Fig. 15). The views of Macar [10], who ascribed the flat to erosion by the headwaters of a stream, are opposed to all that is known of the behaviour of streams in southern England.

The Taplow Terrace.—The next part of the profile is adjusted to the Taplow sea-level. The back-cutting of this stage has overrun three intermediate terraces, those corresponding to the Sleight, Boyn Hill and Iver standstills. It will be clearer to describe the Taplow terrace first (Fig. 16).

From the nick near 300 feet, the profile is well graded for five miles to a lower nick with the Staverton terrace near Buckfast Abbey. The Abbey stands on a terrace, partly artificial, at about 130 feet O.D. Fragments carry down to 90 feet at Riverford Bridge and to 80 feet at Staverton Bridge, both measurements near the upper

edge of the terrace, which has a considerable transverse slope. Below this scraps of the upper edge are usually at 70-75 feet. The most southern noted is at Dittisham.

Terraces between the Ambersham and Taplow.—The final diversion south and the initiation of the gorge which extends from Dittisham to Dartmouth must have taken place when the old Dart nearby was in the Ambersham stage, presumably during or shortly before the Sleight standstill. It is difficult to get evidence in the gorge itself, as its walls descend steeply from 500 or 400 feet to more than 100 feet below sea-level. In places the fall of 600 feet is accomplished in less than three times that distance.

The clue to the over-run terraces seems to lie in a complex gravel-spread at Summerhill Cross, three-quarters of a mile west of Ashburton, which can be dissected into four patches, with heights from south-east to north-west approximately 265, 250, 230 to 240, and 265 feet. The two higher belong to the Ambersham terrace; the lowest can reasonably be connected with the Boyn Hill terrace; that at 250 feet may be Sleight, but the evidence is weak. There is no doubt about the Sleight terrace at Totnes, whence it descends from 195 feet to 160 feet above Dittisham, but links with Summerhill Cross are dubious. At Blackmoor, a mile from Summerhill Cross, a long Boyn Hill terrace, with lower edge from over 200 to 190 feet O.D., overlooks the river. Fragments lead down to 145 feet at Staverton and 137 feet just north of Totnes. From this to the gorge only scraps of the upper edge are seen, apparently on a horizontal segment.

The Iver terrace is little known. It is best seen at Holne Park, where a terrace half a mile long is 218 feet at the north end and 200 feet at the south. At Blackmoor it is about 170 feet. Fragments lead to 105 feet near Totnes, and afterwards suggest a horizontal segment at about 100 feet O.D.

Later Terraces.—The Staverton, Muscliff and Christchurch terraces of the Dart have been described earlier [11, 12].

The position of the final plunge has not been definitely ascertained, but appears to be at Staverton. The lower buried channel reached a depth of 140 feet in Dartmouth harbour.

At Totnes and for a mile and a half below Totnes Bridge the tidal estuary is flanked by a terrace about 12 feet above low tide [13]. This suggests that later the sea rose some feet above the present, corresponding to the 10-foot terrace of Christchurch and Southampton Water. But it is not certain that this low terrace could not be accounted for by accumulation at the existing sea-level.

The Caton Terrace.—An explanation is needed of the lower, or Caton floor of the ancient valley (Fig. 14). For this purpose it is necessary to consider the effect of beheading on a river.

Take first the opposite case where the volume of a river is increased by the entry of a large tributary. Since a large river in steady flow has a flatter course than a small river or, what comes to much the same thing, its approximation to a logarithmic profile has a larger parameter, the water slopes above and below the entry of the tributary should form an angle opening upwards, the opposite of a water nick. A nick travels upstream and this anti-nick would travel downstream, with the well-known result of a "deferred junction." The effect would be most marked when tributary and main river were equal, a condition which seems to have been nearly realised in the case of the Dorset Stour and the Solent river, the junction of which has travelled some 10 miles from the Upper Ambersham standstill to the Iver or 100-feet sea-level [12, p. 99]. The landscape changes referred to by R. E. Horton [14] may have had some effect, but could not have been enough in the Stour-Solent valleys to account for more than a small part of the movement.

Conversely, abstraction of a large proportion of the water would lead to a change of water slopes tending to an angle opening downwards, that is, to a water-nick, which would travel upstream; and the stream below, striving towards a smaller parameter, would reach steady motion by means of a more strongly curved profile, usually requiring excavation of the bed. In the case of the beheaded Dart this should be noticeable in and below the river Yeo, an important tributary of the ancient river.

At the point where the Yeo enters the old Dart valley are paired flats at about 440 feet O.D., which look like fragments corresponding to the Caton terrace. There is a nick in the Yeo somewhat below 500 feet. A curve fits these and the Caton terrace sufficiently well to suggest that it is graded to the 430-feet sea-level. It is inferred that the Caton terrace is the result of diversion of the Dart.

The Yeo now runs through Ashburton in a gorge to join the present river Dart not far below the head of the Staverton terrace at Buckfast. cursory inspection suggests that the lower part of the Yeo is due to capture by a tributary of the Lower Dart during the passage of the Ambersham stage, but this could only be settled by more detailed observation.

Gradients.—In describing the elevated terraces the upper limit is taken in each case at the place where the terrace first appears, that is, the highest point of a complex nick. Longitudinal measurements are taken along the assumed middle line of the corresponding alluvium. Gradients are stated in units per thousand.

The present flood-plain of the 1000-feet standstill is very steep, about 45 per mille. To the old shore-line the length of the elevated terrace, when complete, was about $8\frac{1}{4}$ miles with a fall of 230 feet, averaging five per mille. The flood-plains of the 920-feet and 800-feet are much less steep; the elevated terraces in both cases about seven miles long with average gradients near seven and five per mille respectively.

The coastline of all three of these sea-levels was not far from the metamorphic aureole of the granite. There may have been short horizontal segments of the terraces, but measurements so far available are not enough to determine that it was so.

With the retreat of the sea to the neighbourhood of Teignmouth a radical change took place in the character of the elevated terraces. The rocks over the greater part of their course are softer than the granite and its aureole; and the horizontal segments, where they can be detected, become important. Except in the case of the 690-foot standstill, the position of the mouth is uncertain, but the gradient that matters is that to the head of the horizontal segment, probably not far from tide-head.

The 690-foot elevated terrace, from the 925-foot nick to the old coast, would be some 23 miles long with a fall of 235 feet, averaging two per mille. The 595-foot and 505-feet are less definite, but probably had terraces about 20 miles long with a similar gradient. In all three cases there may have been a horizontal segment of considerable length, so that the gradient of the graded slope would be higher. This was certainly so with the first 430-foot terrace, as its appearance in the Teign valley shows that it must have been horizontal for some miles west of Newton Abbot. From the 680-foot nick the graded slope extended about 10 miles with a gradient of five per mille.

The second 430-foot terrace, marking the main diversion, begins the steep gorge above the New Bridge flats. Its flood-plain falls 120 feet in three-quarters of a mile, a gradient of 30 per mille. It is necessary to go back to the 1000-foot flood-plain to find any section nearly so steep. Incision at the probable point of diversion is estimated as 60 feet. The graded slope of the elevated terrace ended before Shere Wood (Fig. 13) and must be about $5\frac{1}{2}$ miles long with a gradient averaging 4.5 per mille. The Sicilian flood-plain continues the gorge; in little over half a mile it falls about 110 feet, a gradient of 35 per mille. The elevated terrace begins near the entry into the aureole and is still steep at the Bellpool eyots, but soon flattens out, the gradient near New Bridge being under four per mille. From New Bridge to the beginning of the horizontal segment, somewhere near Staverton, say nine miles, the gradient averaged no more than 1.5 per mille.

The Ambersham flood-plain is a mile and a half long, falling about 140 feet to the nick near 310 feet O.D. The position of the head of the horizontal segment is somewhat uncertain, but appears to be some four miles south-east of Totnes. There would thus be a further fall of 120 feet in 16 miles, a gradient of 1.4 per mille.

The lower parts of the later terraces have been so dissected and destroyed that it is difficult at present to make out their slopes. No duplication due to the latest diversion south has been detected. In general the average gradient of the elevated terraces seems to be

between 1.0 and 1.5 per mille. The strong erosion of the Taplow stage has led to a flood-plain five miles long with an average gradient of seven per mille. If a horizontal segment begins near Totnes, the slope of the elevated terrace, eight miles long, would be about two per mille.

Glaciation.—We now return to peculiarities of the profile above 1504 feet O.D. Survey levels make possible a fair picture of the high profiles of the West and East Dart (Fig. 11).

Above the reach graded to 1150 feet the west Dart traverses a marshy area a quarter of a mile long, bearing levels 1518, 1520 and 1517 feet; 200 yards farther upstream is a spot-level 1521. It is difficult to interpret this flat otherwise than as filled-up rock basin. Half a mile farther is level 1584. The slope is then moderate till 1615 feet is reached, when there is a sudden rise to 1658 feet in about 180 yards. The highest point marked is 1727 feet.

On the East Dart a small marshy area bears a level 1519 feet, the next, 1571, being a quarter of a mile upstream. Between is a waterfall, of which a description and photograph have been kindly given by Mr. R. H. Worth. The total fall is about 12 feet, the first nine being a vertical drop. A reach, largely marshy, has levels 1600, 1601, 1605 and 1605 feet along a length of 500 yards. Two miles upstream a marshy strip bears levels 1767, 1770, 1771 and 1779 in 600 yards.

Both rivers appear thus to be ungraded above 1500 feet, but to present in places infilled rock basins and abrupt steps. Such profiles have been discussed by Prof. Cotton [15] and must be regarded as diagnostic of glacier snouts. The area now above 1750 feet is about 40 square miles and would be adequate to produce small glaciers. Colonel Pickard has collected evidence for glacial action on Dartmoor [16], but geomorphology must relegate some of it to periglacial rather than glacial conditions. No doubt the snouts descended lower than 1500 feet on the northern slopes, where Pickard adduces important evidence for a terminal moraine at Taw Marsh, near 1200 feet O.D.

The glaciation may be correlated with the lower buried channel, which is probably later than the plunge. So, too, may some rock fans at the mouths of tributaries, of which the most obvious is that at the mouth of the Mardle.

Nicks and Eyots.—It was discovered by Miss Boswell that in the river Test many of the nicks are complex. The elevated terraces are given off at an upper, primary nick; but the water profile shows a lower secondary nick, approximating to the intersection of the curves of the graded reaches above and below. In the Boyn Hill-Iver nick on the Test the distance between the primary and secondary nicks is as much as two miles. The cause appears to be rapid removal of permeable flint gravel overlying chalk [17].

It has since been found that this complexity explains difficulties met with in mapping the terraces of the Hampshire Avon and Dorset Stour, where differences existed between the positions of nicks as mapped by terraces and as calculated from flood-plain curves. At the Canford nick on the Stour and at the Watton's Ford nick on the Avon, the shape appears to be that of the complex nicks on the Test, though precise measurements are lacking. In both eyots are present. The finest set of eyots on the Test is the series, nearly a mile long, at the Boyn Hill-Iver nick.

It has already been mentioned that some of the nicks on the Dart seem to be similar. In only two places are the calculated curves sufficiently detailed for assurance. It is, however, probable that all the Dart nicks are complex. Certainly most are accompanied by eyots.

The best noted is at the Ambersham-Taplow nick, by a road below New Bridge (Fig. 13). Though the gravels have been greatly disturbed by tinning, it is clear that the elevated terrace starts about 300 yards below the bridge. The curves, however, intersect three-quarters of a mile farther down, below a series of eyots, where the Ambersham terrace is 10 feet above the local flood-plain. It is inferred that there is a secondary water-nick here.

The explanation offered for the form of the nicks on the Test is also satisfactory for the nicks on the Dart. The gravels are, and probably were, highly permeable, resting on almost impervious rock.

A majority of the numerous eyots of the Dart occur at nicks and must be regarded as remnants of terraces, but there are some found on graded reaches. One, at least, Wellsfoot Island (Fig. 13) is built of boulders and gravel brought down by a steep tributary and deposited opposite its mouth.

Subaerial or Marine Planation.—In the history of the Dart no trace has been found of any feature resembling a subaerial peneplain, though it is still possible that something of the kind may have existed in the obscure period between the completion of the folding and the formation of the 1150-foot platform.

On the other hand, evidence has accumulated for the existence of marine plains. Lines of cliff have been followed in Devon and Cornwall for parts of those with upper limits about 340, 430, 505, 530, 595, 690, 820, 920, 1040 and 1160 feet. Shingle has been found on those of 340, 430, 505, 920 and 1040 feet. In south-east England shingle has been found on platforms believed to be equivalent to the 595 and 690-foot platforms of Devon. The curves obtained by Hollingworth [6] confirm generally and extend the series. Platforms at 280 metres, believed to be marine, are recorded over much of France, in Algeria and in the Dobrudja [18]. By altimetric methods platforms have been determined like the

1000-feet. It is not likely that observations based on small-scale maps could distinguish between the 920-feet and 1000-feet levels, but there is a probability that such sea-levels affected much of the Mediterranean region. If so, later sea-levels should also correspond to those of southern England.

Only one case has been found in which the methods are detailed enough to allow comparison. Ball obtains the following probable levels for the Mediterranean [19]. In the table feet are added for ease of comparison with the writer's results :—

				<i>Sea Level</i>		
				<i>Metres</i>	<i>Feet</i>	
Middle Pliocene	...	...	...	180	591	595 feet
Late Pliocene	...	...	...	154	505	505 feet
				129	423	430 feet
Early Pleistocene	...	...	...	103	338	Sicilian
				72	236	Upper Ambersham
				57	187	Ambersham
Chellean	...	...	...	41	134	Boyn Hill
Acheulean	...	...	...	25	82	Iver
Early Mousterian	...	...	...	18	59	Taplow
Middle Mousterian	...	...	...	—12	—39	Upper Buried Channel
Late Mousterian	...	...	...	16	52	} Muscliff
Early Sebilian	...	...	...	13	43	
Middle Sebilian	...	...	...	3	10	Christchurch
Late Sebilian	...	...	...	—43	—141	Lower Buried Channel

There is nothing equivalent to the Sleight level and the Staverton terrace would be buried. The similarities are too great for mere coincidence.

The most important of these standstills, in Britain and the Mediterranean, is that at 180 metres. Measures given by Jovanović for the Vardar (19a) are consonant with the grading of the river, between the heights of 215.1 and 261.0 metres, to that sea-level.

The 280-metre and 300-metre platforms are regarded by French authors as Pliocene. Barrow and Reid thought the high platforms to be Miocene, and are supported by attribution of the 700-feet platform to the Diestian. Mr. Kennard has pointed out to the writer that the exact nature of the relationship of the Diestian fossils of Lenham to the neighbouring platform is not yet certain. Further evidence is desirable.

It is no longer easy to accept the striking interpretation by W. M. Davis in Fig. 1, p. 292, of the *Quart. Journ. Geol. Soc.*, vol. 65 (1909), explaining the landscape of Devon and Cornwall by two cycles of subaerial denudation surrounding a monadnock. The lower cycle is represented by the marine 430-feet and Sicilian beaches. The upper may be a combination of the 1000-feet, 920-feet and 800-feet marine platforms. The monadnock becomes a sea-bottom exposed in Oligocene times and subsequently tilted. It would seem that the peneplain may ultimately disappear altogether from English landscape.

In August, 1911, L. Sawicki, after visiting Wales with Davis, travelled through Devon and Somerset with three French geographers. In 1912 [20] he stated that the Dartmoor granite was surrounded by platforms rising from 500 to 800 feet. He considered the numerous plateaux of south-west England to be peneplains and held that marine origin was disproved by constant change of level, which, he said, was often developed up to 100 to 300 feet in from 10 to 30 kilometres. This is the superficial impression given anywhere to a traveller in south-west England, but has turned out to be fallacious wherever detailed examination has been undertaken.

The contrary opinions earlier expressed by Clement Reid [21] and Barrow [22] were based, not on passing glimpses, but on six-inch to the mile mapping.

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THE OSTRACOD GENUS *CYPRIDEA* AND THE ZONES OF THE UPPER AND MIDDLE PURBECKIAN

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SUMMARY

The nomenclature of the genus *Cypridea* is clarified, and a valid genoelectotype is selected. The shell characters of the genus are described. Stratigraphically significant species of the Upper and Middle Purbeck Beds are described, and their distribution incorporated in a revised zonal scheme.

1. THE GENOTYPE

OSTRACODS of the genus *Cypridea* have long been known as characteristic of the Purbeck and Wealden Beds of England and of deposits of a similar age in Germany and America.

The genus *Cypridea* was proposed by Bosquet in 1852 for eight or nine species, which he did not mention by name. He referred to them as having been described by Sowerby, Roemer and Dunker from the Wealden of England and Germany, and by them assigned to *Cypris*. Bosquet noted that these species differed from the living *Cypris* in possessing on the antero-ventral margin "un petit crochet ou prolongement en forme de bec. Cette différence me semble être d'une importance suffisante pour l'établissement d'un nouveau genre, et je propose de donner à ce genre le nom de *Cypridea*." In a footnote he mentions that a considerable number of new species from the Wealden were soon to be described by "M. le professeur E. Forbes, de Londres." Actually Forbes never lived to describe these species, though in 1855 Sir Charles Lyell published woodcuts of some of them in the fifth edition of his *Manual of Elementary Geology*, with Forbes' name attached. One, designated "*Cypris punctata*, E. Forbes," was quoted from the Lower Purbeck.

Thirty years later Professor T. Rupert Jones (1885*) in a well-known paper on the Purbeck Ostracoda described the genus *Cypridea* in greater detail, and defined several of Forbes' species, including a species he identified as *Cypridea punctata* (Forbes), which, however, he quoted as being especially characteristic of the Upper and Middle Purbeck, and unknown in the Lower.

* For list of References, see p. 149.

Mr. F. W. Anderson (1939) in his revision of the Wealden and Purbeck Ostracoda has designated *Cypridea punctata* (Forbes) as the genotype. However, species which were not included under the generic name at the time of its original publication are excluded from consideration in determining the types of genera (under Article 30 of the International Code). *Cypris punctata* Forbes was not published until three years after Bosquet's proposal for *Cypridea*. Anderson's designation is therefore invalid. The genolectotype will have to be selected from the following species of "*Cypris*" which had already been established by Sowerby, Roemer or Dunker before 1852, which possess the "petit crochet" of Bosquet, and which therefore constitute the genosyntypes:—

(a) J. de C. Sowerby first described "*Cypris Faba*?" in vol. 5 of the *Mineral Conchology of Great Britain* (1825). Fitton altered this name to *Cypris Valdensis* in 1836 (as M. Deshayes had by then pointed out to him that it could not be the *Cypris Faba* of Desmarest) and Sowerby described and figured it under that name in the appendix (1836, p. 344, pl. 21, fig. 1¹), and also described three other species: *Cypris tuberculata*, *C. spinigera* and *C. granulosa*.

(b) Roemer (1839) described and figured species from Germany he identified with *C. valdensis*, *C. tuberculata* and *C. granulosa*, and also two new species: *C. oblonga* and *C. striato-punctata*.

(c) Dunker (1846) again described these five German species under the same names, and added three new species, *C. laevigata*, *C. rostrata* and *C. pinnaeformis*.

C. valdensis would not make a good choice as the genotype of *Cypridea*, since in 1939 Anderson chose it as the type of a new genus, *Cyamocypris*. I am here designating *Cypris granulosa* Sowerby as genolectotype. Material collected by Fitton from the type locality in the Vale of Wardour is preserved in the collection of the Geological Society, which is now incorporated in the collections of the Geological Survey and Museum.

2. REMARKS ON CERTAIN RELATED GENERA AND SUB-GENERA

Genera and sub-genera so far proposed related to *Cypridea* are listed as follows:

- i. *Pseudocypridina* Roth, 1933. Distinguished by the absence of a "notch." Genotype: *P. piedmonti* Roth, 1933. See p. 146.
- ii. *Ullwellia* Anderson, 1939. Distinguished by reversal of valve overlap. Genotype: *U. menevensis* Anderson, 1939.
- iii. *Langtonia* Anderson, 1939. Distinguished by smooth, non-punctate surface. Genotype: *L. setina* Anderson, 1939. Kellett (personal communication) considers *Langtonia* to be a synonym of *Pseudocypridina*. *Pseudocypridina* is faintly punctate;

¹ Jones subsequently (1878) maintained that "unfortunately another form was confused with it." This he identified as his *Cypridea austeni*.

both *Pseudocypridina* and *Langtonia* have beak and notch much reduced, and the postero-ventral projection of the larger valve absent. I have followed Kellett in regarding them as synonymous. See p. 146.

iv. *Morinina* Anderson, 1939. Distinguished by dorsal sulcus, large scattered normal pore canals, and smooth surface. Genotype: *M. dorsispinata* Anderson, 1939.

v. *Cyamocypris* Anderson, 1939. Distinguished by large size, thin shell, and exaggerated selvage. Genotype: *Cypris valdensis* Fitton, 1836. Anderson, when proposing this genus, described only the new species *C. tumescens*. The fact that *C. valdensis* possesses the characters claimed for the genus remains to be demonstrated.

vi. *Paracypridea* Swain, 1946. Distinguished by shape and overlap. The muscle scar as figured differs also from *Cypridea*. Genotype: *Cypridea* (*Paracypridea*) *obovata* Swain, 1946.

Roth's and Anderson's names were given generic rank by their authors. Martin (1940) reduced all these to the synonymy of *Cypridea*. I prefer to regard them as sub-genera. On the other hand, Swain introduced his name as a sub-genus. This I would raise to generic status, differences of muscle scar and shape seeming of greater importance than differences of degree in the development of other characters.

3. THE ZONES OF THE MIDDLE AND UPPER PURBECKIAN

Cypridea occurs in freshwater or estuarine beds. It occurs mainly in strata of Purbeck or Wealden age, and has been recorded from these strata wherever they occur in England, and also from Germany (see Koert, 1898; Wicher, 1940, and Martin, 1940) and America (see Jones, 1893; Roth, 1933; Harper and Sutton, 1935; Peck, 1941, and Swain, 1946).

Cypridea spinigera (Sow.) is unique in having been recorded from strata of as widely differing ages as Oxford Clay and Oligocene (see Jones, 1888). No recent work however has confirmed Jones's identifications.¹

Certain of its species are short-lived, and exhibit well-marked evolutionary trends. They therefore lend themselves well to stratigraphical use. Several zonal schemes based on *Cypridea* and other ostracods have been proposed since the time of Forbes, as shown in the table on p. 128.

In the arrangement here adopted, certain nomenclatorial changes are proposed, but Anderson's zonal scheme is retained, and is expected to prove workable throughout the English province.

¹ Note added in proof: Swain, 1949, confirms the occurrence of *Cypridea* in Tertiary rocks.

FORBES, 1850 (MS.) ; Lyell, 1855. Damon, 1884, pp. 201-9	ARKELL, 1933 (based on Jones, 1885) Arkell, 1933, p. 518 Arkell, 1947, p. 113 Davies, 1947, p. 343	ANDERSON, 1940	SYLVESTER-BRADLEY (as expanded below)	
UPPER	{ <i>Cypris gibbosa</i> Forbes <i>Cypris tuberculata</i> Sow. <i>Cypris leguminella</i> Forbes	<i>Langtonia setina</i> Anderson	<i>Cypridea</i> * <i>setina</i> (Anderson)	<i>C. setina</i> s. str.
		<i>Cypridea punctata</i> (Forbes)		<i>Cypridea</i> * <i>rectidorsata</i> S.-Bradley
MIDDLE	{ <i>Cypris striato-punctata</i> Dunker <i>Cypris fasciculata</i> Forbes <i>Cypris granulosa</i> Sow.	<i>Cypridea granulosa</i> var. <i>fasciculata</i> (Forbes) <i>Metacypris forbesii</i> Jones	<i>Cypridea</i> * <i>granulosa</i> (Sow.)	<i>C. fasciculata</i> * (Forbes)
		<i>Cypridea punctata</i> (Forbes) <i>Cypridea ventrosa</i> (Jones)	<i>Cypridea granulosa</i> (Sow.)	<i>C. granulosa</i> s. str.
LOWER	<i>Cypris purbeckensis</i> Sow. <i>Cypris punctata</i> Forbes	<i>Cypris purbeckensis</i> Sow. <i>Candona ansata</i> Jones	None chosen. Purbeck species placed in the genera <i>Cypris</i> and <i>Candona</i> by Jones are thought to be facies fossils. I have found them rarely in the Middle and Upper Purbeck of Dorset. At Aylesbury they are abundant, and associated with <i>Cypridea</i> spp.	

* For stratigraphical purposes a binomial nomenclature is adopted rather than the quadrinomial form used in the systematic part.

Within these zonal divisions other species of *Cypridea* are restricted to smaller limits :—

	ZONES	SUB-ZONES	OTHER SPECIES
Upper Purbeck	<i>C. setina</i> (Anderson)	<i>C. setina</i> s. str.	<i>C. adjuncta</i> Jones
		<i>C. rectidorsata</i> S.-Bradley nov.	<i>C. propunctata</i> ¹ S.-Bradley nov.
Middle Purbeck	<i>C. granulosa</i> (Sowerby)	<i>C. fasciculata</i> (Forbes)	-----
		<i>C. granulosa</i> s. str.	<i>C. dunkeri</i> Jones <i>C. posticalis</i> Jones

Reference is made to all these species in the systematic descriptions that follow.

C. setina has a wide distribution, and may be taken to indicate the upper limit of the Upper Purbeck, a zone corresponding to the "Paludina Clays" of Bristow and Fisher (1857) together with the upper part of the underlying "Upper Cypris Clays and Shales."

C. rectidorsata occurs in the lower part of the Upper Purbeck, which, in Bristow and Fisher's sections, includes the lower part of the "Upper Cypris Clays and Shales" and the underlying strata described as the "Unio Beds."

In Dorset, *C. fasciculata* replaces *C. granulosa* from an horizon near the top of Bristow's "Cherty Freshwater" beds. The sub-zone of *C. granulosa* sensu stricto can therefore be said to include the lower "Cherty Freshwater" beds and the "Marly Freshwater" beds which underlie them, extending to the base of the Middle Purbeck. Bristow marks the junction of Lower and Middle Purbeck as occurring either in the middle or at the top of the "Marly Freshwater" beds, the position varying according to locality. According to the evidence provided by *C. granulosa*, however, he has in most instances placed this junction too high; it would be more correctly represented at the base of the "Marly Freshwater" beds.

In the Vale of Wardour the junction between the two Middle Purbeck sub-zones can be recognised in the Teffont Evias quarry.

Martin's (1940) revision of the ostracods of the German Purbeck-Wealden includes *Cypridea granulosa*, "*C. dunkeri*?", "*C. mammillata*," and *C. posticalis*. From the illustrations it would seem that "*C. dunkeri*" and "*C. mammillata*" are varieties of

¹ *Cypridea propunctata* (= *C. punctata* auctorum) is a bad zonal index, for it is difficult to distinguish from many other punctate but otherwise unornamented species of *Cypridea* occurring throughout the Middle and Upper Purbeck, and extending into the Wealden—e.g. the "*C. punctata*" of Martin (1940), which extends in range well below *C. granulosa*. (In the Thören boring, 778-789 metres.)

C. fasciculata. The vertical distribution of these species in the Thören boring is given as follows :

<i>C. granulosa</i>	768-781 metres.
" <i>C. mammillata</i> "	764-771 metres.
" <i>C. dunkeri</i> "	771 metres.
<i>C. posticalis</i>	779 metres.

Martin ascribes 750-772 m. to the Wealden, 773-789 m. to the Purbeck. In England the species I have quoted are all characteristic of the *C. granulosa* zone. I would therefore correlate 764-781 m. with the British Middle Purbeck.

4. SYSTEMATIC DESCRIPTIONS

Class CRUSTACEA. Order OSTRACODA. Sub-order
PODOCOPA.

Super-family CYPRACEA¹ Ulrich and Bassler.

Family ? CYPRIDAE Zenker.

Sub-family CYPRIDEINAE Martin, 1940

(Rostrocyprinae² Anderson, 1939).

Genus CYPRIDEA Bosquet, 1852.

Cypris auctorum.

Cypridea Bosquet, 1852.

Cytherideis Jones, 1856.

Cytherideis Jones, 1857 (pars).

Cypridea Martin, 1940.

Genolectotype : *Cypris granulosa* Sowerby, 1836.³

Diagnosis :

Carapace bearing on the antero-ventral margin of each valve a projection termed a "beak," often prominent.⁴ Behind the beak there is a furrow or "notch" extending upwards from the ventral margin.

Description :

Carapace oval or oblong, inequivalve, either right or left valve being the larger, and overlapping the other on all margins. In side view the position of greatest height is at the centre or within the anterior half of the shell. The shape varies greatly, as do the strength and length of the notch and beak. The surface may be smooth, punctate or reticulate, and may bear spines or tubercles.

¹ Proposed as "CYPRIDACEA." Here respelt to conform to the typical family "Cypridae" based on the genus "*Cypris*."

² This name, not being based on any genus, is invalid.

³ First designated by Sylvester-Bradley, 1947.

⁴ Swain (1946) has referred to that part of the carapace anterior to and including the beak as the "hood."

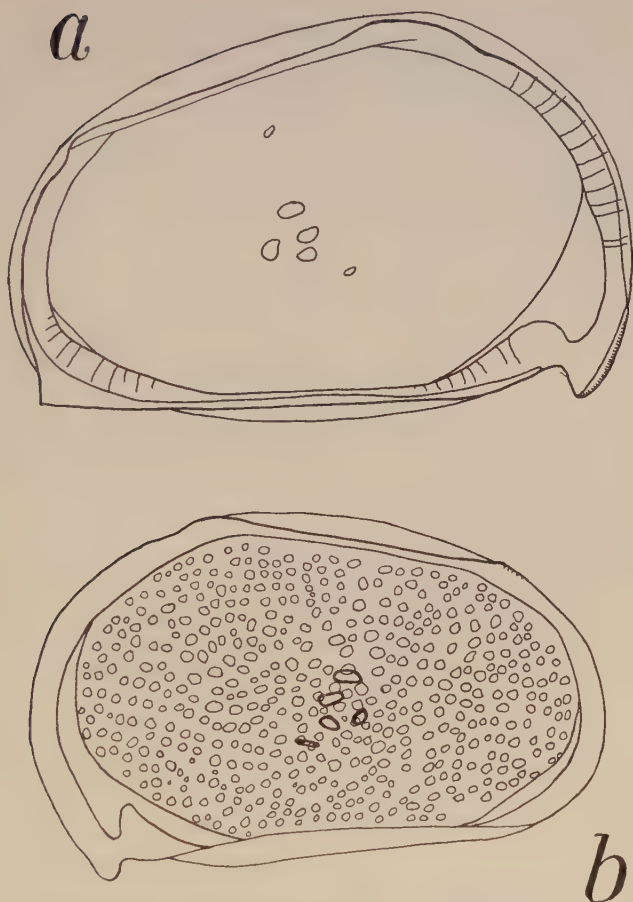


FIG. 17.—*Cypridea propunctata*, (a) left valve ; (b) right valve ; seen from the inside by transmitted light. Upper Purbeck, Osmington Mills (OMA 22), (a) Brit. Mus. No. In.39177 ; (b) Brit. Mus. No. 39176. $\times 90$.

The duplicature¹ is bilamellar. The selvage bears a delicate striated fringe. When the larger valve is viewed from the side by transmitted light, the selvage can be seen in the anterior part of the shell running parallel to the outer margin (here formed by a flange), but a short distance inside it (Fig. 17a and Fig. 18). In the antero-ventral part, as it approaches the beak, the selvage forms the outer margin. In the ventral region it is strongly developed,

¹ The terminology and definitions used are those explained in Sylvester-Bradley, 1941 (2), pp. 7-11.

but infolded, so it can only be seen in ventral view (Plate 3, Fig. 3). At the apex of the beak it forms a small, open tube. In the postero-ventral corner it is produced into a sharp projecting angle. Posteriorly it runs parallel to the outer margin, a short distance inside it, and dorsally merges into the hinge structure, as described below.

The selvage of the smaller valve is not infolded to the same extent as that of the larger, and itself forms the outer margin at both ends (Fig. 17b). Therefore, in lateral view the flange can be seen lying *inside* the selvage for a short distance at the anterior end. When the valves are closed the selvage of the larger valve overlaps that of the smaller (Plate 4, Fig. 3a). The selvage is particularly strongly developed in the species *C. (Cyamocypris) tumescens* (see Fig. 18), and has been well illustrated by Anderson (1939, Pl. 13). Anderson sometimes uses the term "flange" and sometimes "fringe" for what is here described as the selvage.

There is a well-marked antero-ventral vestibule. The line of concrescence runs parallel to the outer margin in the neighbourhood of the beak, thus giving the vestibule a sinuous shape. There is a narrow postero-ventral vestibule.

The radial pore canals are simple and almost straight (Fig. 19). They run from the line of concrescence (or inner margin, where there is no vestibule) to some point on the outer surface between it and the flange. They are slightly dilated at their point of exit. The normal pore canals are often obscured by ornament. When there are puncta, these appear to surround the pores.

The hinge line is straight, and occupies about half the length of the whole carapace. As in the Cytheridae, it is divided into three elements, anterior, median and posterior. In both valves the shell is sharply infolded towards the hinge margin, thus forming a sulcus along the dorsal margin, which can be seen when the complete carapace is viewed from above (Plate 4, Fig. 3b). The larger valve (Plate 4, Fig. 5) has along the median portion of the hinge a groove, which at each end is dilated and makes a scalloped recess. At the anterior end the selvage is swollen and overhangs the recess (the "knurling" of Anderson, 1939), partly hiding it in lateral view. The posterior end is even more obscured by the swollen selvage which overhangs it ("flexure," Anderson, 1939).

The median portion of the hinge of the smaller valve (Plate 4, Fig. 4) bears no groove. The posterior part of the hinge projects in the form of a swollen cusp which fits into the posterior recess of the larger valve. In exceptionally well-preserved specimens it is sometimes possible to distinguish faint crenulations on this cusp, suggesting that it may become denticulate in some species. The anterior part of the hinge also projects, and fits the anterior recess of the larger valve, but it is not swollen, and has a slightly concave ventral surface.

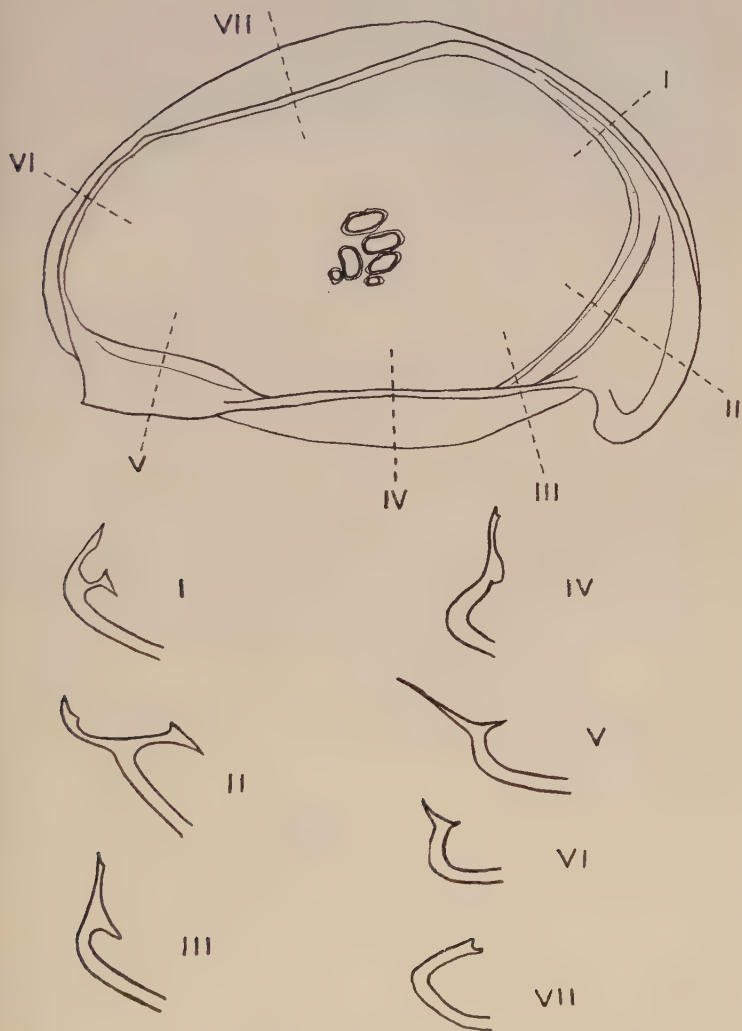


FIG. 18.—*Cypridea* (*Cyamocypris*) *tumescens*, left valve. Seen from the inside, with diagrammatic reconstructions of sections of the Shell, to show marginal details. Middle Purbeck (Cherty Freshwater Beds) near Portesham. Brit. Mus. No. In.39179. (Specimen is 1.40 mm. long.)

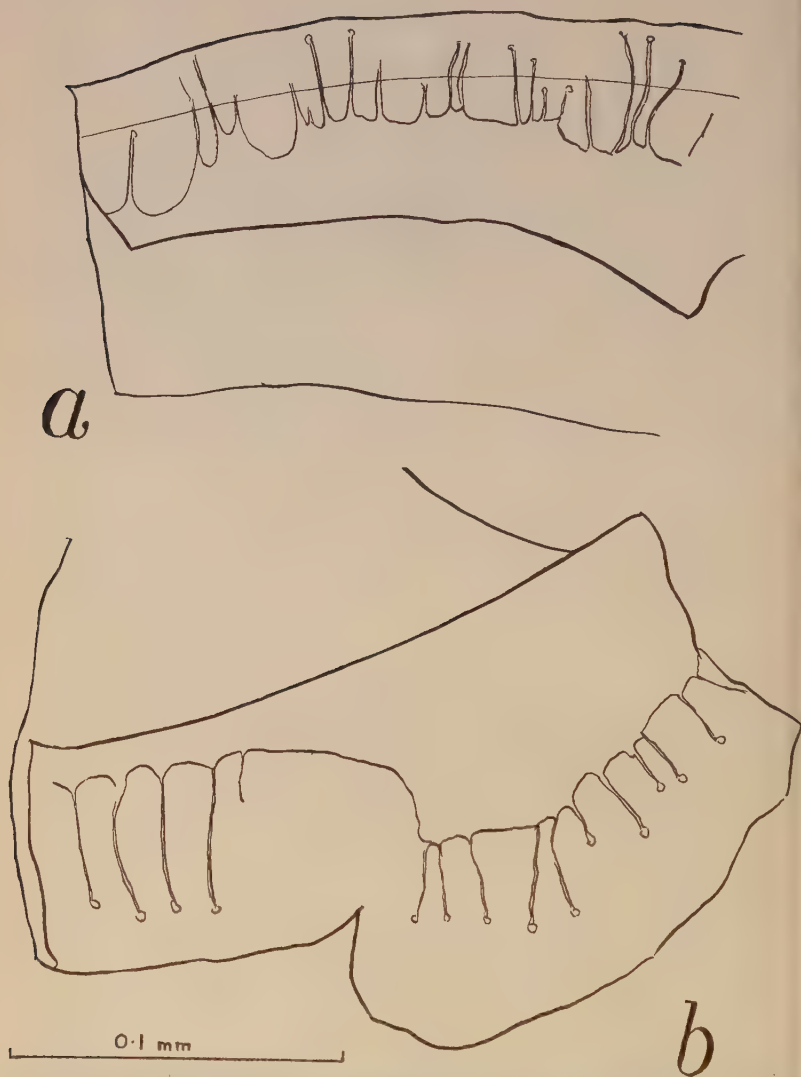


FIG. 19.—*Cypridea propunctata*, fragments of left valve, seen by transmitted light, and highly magnified, to show radial pore canals. Upper Purbeck, Osmington Mills (OMA 22).

The muscle scar pattern appears to be constant for the genus, and consists of four oval scars in the centre of each valve (Figs. 17 and 18), three in front with their longer axis horizontal, and one behind in which it is vertical. Occasionally, in translucent specimens, the muscle scars can be seen through the shell from the outside (Plate 4, Fig. 1). In the most perfectly preserved specimens it is possible to detect two additional scars, both narrow; one lies to the front and below the main group, the other lies directly above the main group, about half the distance between it and the dorsal margin (Fig. 17).

Sub-genus CYPRIDEA *sensu stricto*

Cypridea Jones, 1885.

Cypridea Anderson, 1939.

Left valve the larger. Surface punctate or reticulate. May or may not bear granules, tubercles, or spines.

Cypridea (*Cypridea*) *granulosa* (J. de C. Sowerby).

Cypris granulosa J. de C. Sowerby, 1836 (not *Cypris granulosa*, Robertson, 1880).

Cypris granulosa Mantell, 1838, vol. i, p. 344, tab. 46, fig. 9.

? *Cypris granulata* Forbes, in Lyell, 1855, p. 295, fig. 337c.

Cypridea granulosa Jones, 1885, pl. viii, fig. 21.

Cypridea granulosa paucigranulata Jones, 1885, pl. viii, figs. 18-20.

Cypridea granulosa Martin, 1940, p. 289, pl. 1, figs. 5-8.

Description

The left valve is the larger, and overlaps the right valve, especially in the ventral region. In general proportions the two valves are similar. The beak, notch and postero-ventral projection are not developed so strongly as is common in the sub-genus. There is a definite antero-dorsal angle.

Dimensions of neotype (complete carapace): length 1.15 mm.; height, 0.78 mm.; width, 0.58 mm. Proportions: length: height: width, 1.47:1:0.74.

Both valves bear a number of rounded tubercles of various sizes, more strongly developed towards each end of the carapace. The extent of the variation is illustrated by a comparison of the two valves figured (Plate 3, Figs. 1 and 2). The number of tubercles is relatively stable (usually about 32), but the size and the height vary not only from specimen to specimen, but also between individual tubercles on the one carapace. Not infrequently two tubercles grow so close together as to coalesce. Those near the margin and about the centre of the valve are slight; they can only be discerned in strong oblique illumination after the shell has been coated with an opaque white layer of ammonium chloride sublimate to reduce translucence and reflection.

The surface of the valves is punctate. The size of the puncta is irregular, as is their shape. There is a tendency for those near the periphery of each valve to be arranged in lines parallel to the margin.

The details of contact margin, hinge margin and muscle scars are as described for the genus.

Types

Neotype and topotypes : Geol. Soc. colln. No. 2678 (housed in Geological Survey Museum, London) : "Between Dallard's Farm and Catherine Ford."

Figured Specimens.

This paper, fig. 20 (neotype). See above.

Jones, 1885, pl. viii, fig. 21, and this paper, fig. 21 : Brit. Mus. No. In 39024 (Jones's No. 229.13). For locality see below under "Remarks."

This paper, pl. 3, figs. 1 and 3b : Brit. Mus. No. In 39169 ; pl. 3, figs. 2 and 3a : Brit. Mus. No. In 39170. Locality (both specimens), road cutting at Poxwell, Dorset, "Marly Freshwater Beds," Bed 12a (see Appendix).

Subspecies and Variation

The above description applies to *C. granulosa* sensu stricto, which is characteristic of the lower part of the Middle Purbeck. At higher levels, the species becomes variable, and subspecies may be distinguished. Trends are toward increase in size of the carapace ; unequal development of the valves (the right being considerably the smaller, with a pronounced swelling of the posterior dorsal margin, the left developing a short, straight, median portion to the dorsal outline) ; reduction in number of tubercles ; restriction of tubercles to each end of the carapace ; increase in size of tubercles. These trends are exemplified by the specimen figured (Plate. 3, Figs. 4 and 5).¹ Two names have been proposed for subspecies of this genus : *C. fasciculata* (Forbes) and *C. mammillata* Martin (1940, pp. 292-3 ; Plate 2, Figs. 18, 19). Recently (Sylvester-Bradley, 1947) I have speculated on a possible genetic explanation of this variation series.

Remarks

One of the localities that Fitton (1836, p. 260) mentions for *C. granulosa* is "between Dallard's Farm and Catherine Ford" (Vale of Wardour). Specimen 2678 (Geol. Soc. colln., now in the Geological Survey and Museum) is labelled : "Purbeck Stone.

¹ From Bacon Hole, Dorset. Field ref. No. BH 37. A bed of shale with "perished shells" and "beef" 2 feet 6 inches thick, the top 4 feet 6 inches below the lower "Pecten" Bed, the bottom 5 feet 4 inches above the Cinder Bed.

Dimensions : Left valve (fig. 1, Brit. Mus. No. In 39173) : length, 1.20 mm. ; height, 0.88 mm. ; width, 0.40 mm. Right valve (fig. 2, Brit. Mus. No. In 39174) : length, 1.15 mm. ; height, 0.77 mm. ; width, 0.30 mm.

Proportions (complete carapace) : length : height : width, 1.36 : 1 : 0.74.

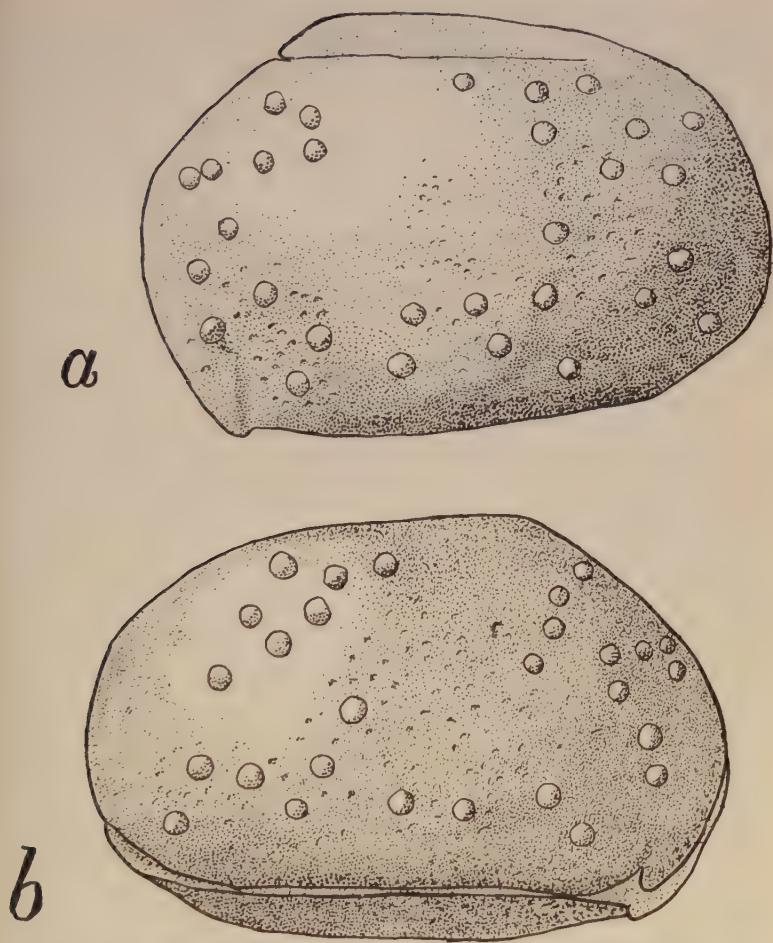


FIG. 20.—*Cypridea granulosa* (Sow.), Neotype; (a) left valve; (b) right valve; seen from the side. Geol. Surv. and Mus. colln., No. 2678. Vale of Wardour. $\times 70$.

Betn. Dalrd. and St. Catherine Ford.” It is a small slab of ostracod limestone, and was collected by Fitton himself. It was part of the material examined by him and by Sowerby when preparing his classical monograph (Fitton, 1836). Ostracods extracted from this specimen are therefore topotypes, and one specimen I have selected as a neotype (Fig. 20).

It is fortunate that type material is available, for the first analyses of this species and the varieties leading to *C. fasciculata* given by

Jones (1885, pp. 340-2) are not very easy to interpret. The most noticeable trend (as mentioned above) is the tendency for the tubercles or "granules" to be reduced to two groups (or "fascicules"), one at each end of the shell. As Jones puts it: "The number of granules in these local groups is variable . . . Sowerby's type-figure has many granules, some coming near to the middle of the valve; other specimens collected by Fitton and labelled with Sowerby's name have very few granules. There is no line to be drawn . . . between the multigranulate and paucigranulate modifications, but it will be convenient to recognise the varieties."

He says: "*C. granulosa* . . . is decidedly the *fasciculata* of E. Forbes," but earlier: "the ordinary multigranulate forms divide themselves into the common variety *fasciculata* (Forbes), and the rarer and earliest named *granulosa* of Sowerby with the granulation covering almost the whole surface."

He also introduces a new variety of his own, *paucigranulata*. This, from the text, appears to be based on specimens from three localities: (a) from Durlston Bay, specimen X_B $\frac{4}{5}$ (Geol. Surv. Mus.), in which the valves are "mostly paucigranulate; one, at least, has the hinder fascicule obsolescent. They have a coarsely punctate or subreticulate surface." (b) From Dashlet (Vale of Wardour), where the specimens are "strong, squarish" and "convex" and "have very few tubercles, only five or even four in the fascicules." The punctuation is modified, being "partially regular" towards the anterior half of the shell, "the pits . . . being oblong and even elongate, curving round in front and radiating backwards a little way from the anterior group of five granules." (c) From "Whitchurch, in Bucks." Two specimens from this third locality are figured (Jones, 1885, pl. viii, figs. 18-21). One of the two specimens is still to be seen in the British Museum (No. In 39024; this is Jones's Fig. 21). The other specimen is unfortunately lost. The following three problems are raised by these figured specimens:

First, the locality and horizon are obscure, as has already been noticed (see Merrett, 1924, and Arkell and Sylvester-Bradley, 1941). There is an error in this previous note of mine on this locality. On p. 326 the label on the specimens is said to read "Whitchurch, Wilts." Actually, Jones's original label reads—"229. *Purbeck*. ? *Whitchurch*, *Hants*, 'Fitton' 17 $\frac{3}{5}$." It seems certain that the specimens did *not* come from Whitchurch, Bucks. Jones (1885, p. 341) no doubt altered the locality from "Whitchurch, Hants" to "Whitchurch in Bucks" because the Whitchurch in Buckinghamshire is the only one of the many villages bearing that name near which Purbeck Beds are known to be exposed. He omitted the question mark on the original label. Beds of the horizon of this species have never yet been found in Buckinghamshire. I have investigated the Purbeck of Whitchurch (Bucks) with some care. With the aid of a trial pit I succeeded in exposing a section passing

from the highest beds I could discover, through the whole sequence preserved, to the top of the Portlandian. The beds were comparable with those in a similar position at Swindon (see Sylvester-Bradley, 1941 (1)). There was nothing comparable with the Middle Purbeck of Wiltshire or Dorset.

From the matrix of the slab "229" (preserved in the British Museum, No. I 1635), from which Jones's specimens were obtained, it seems more likely that it came from the Vale of Wardour.

The second problem that is raised by these specimens is their identification as Jones's variety *paucigranulata*, for not only do they exhibit no "modified punctuation" when comparing them with *granulosa*, but also, in actual fact, they are not "paucigranulate" at all. Jones's Fig. 18, it is true, shows only six "granules" in the anterior "fascicle" and five in the posterior, but this must be due to an oversight, for although this specimen is lost, that shown as Jones's Fig. 21 (Brit. Mus. No. In 39024, Jones's No. 229.13), when turned over, proves to be a perfectly typical specimen of *Cypridea granulosa* (Sow.), complete with its whole complement of tubercles (see Fig. 21b). Moreover, the original slab "229" from which Jones's specimens were extracted (Brit. Mus. No. I 1635), after being crushed and washed, has produced some thousands of other specimens, all typical *granulosa*. Jones mounted individuals taken from this slab on spots of gum on a cardboard slide preserved in the British Museum (I 1667). When examined in 1940 many of the specimens had come away from the gum and were lost (as No. 229.2 of Jones's Figs. 18-20), or were broken. All those left, however, were multigranulate. Jones's 229.13 of Fig. 21 was removed to a safer type of slide, and now bears the Brit. Mus. number quoted above.

Jones did not claim that his Fig. 21 was a specimen of *paucigranulata*, although it is on the same slide and from the same slab of rock as the missing specimen of Figs. 18-20. It is therefore possible that he thought he had the typical *granulosa* and the var. *paucigranulata* both from the same horizon. However, he states that the "paucigranulate variety occurs plentifully" (p. 341); therefore he must have failed to notice the granules. This could easily occur, for he only looked at the specimens weathered out on the surface of the slab, which must have been worn. The preservation is not very good, and the granules, especially those over the central portion of the carapace, are always shallow, and only stand out in a strong oblique illumination.

The specimens figured by Jones as var. *paucigranulata* nov., from which one would normally have chosen a lectotype, must therefore be synonymous with the typical *C. granulosa* (Sow.). If *paucigranulata* is to stand as species, sub-species or variety, its type must be chosen from specimens from the localities (a) or (b) as listed above.

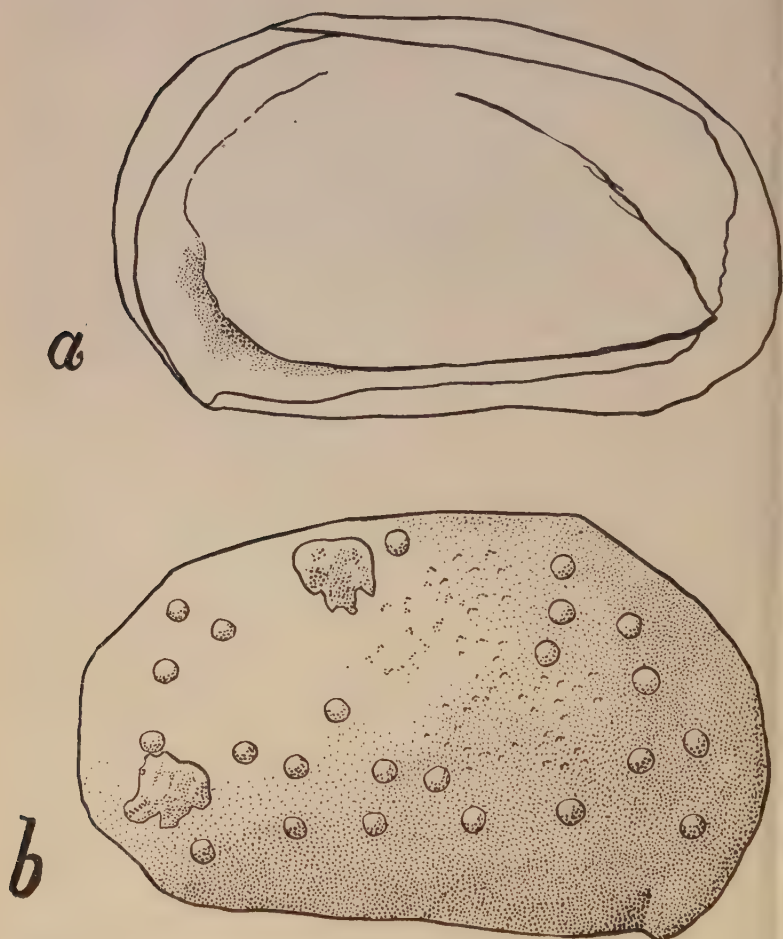


FIG. 21.—*Cypridea granulosa* (Sow.). Jones colln. No. 229.13. (Brit. Mus. No. In.39024): (a) This is the view figured by Jones (1885) as Pl. 8, fig. 21. It consists of three valves, nested one inside the other; (b) The same specimen seen from the outside. $\times 75$.

The third problem centres on Jones's Fig. 21, which purports to show the contact margins of *Cypridea granulosa*. The figure is entirely misleading. The specimen consists of three separate valves, nested one within the other, and it is the successive edges of these shells which are figured as if they were ridges and grooves of the contact margin (see Fig. 21a).

Related American Species

In addition to noting the wide distribution of the species in Europe (see above, pp. 127-30), it is interesting to remark that related species apparently occur in America. A recently described American Mesozoic ostracod, *Cypridea anomala* Peck, shows the same tendency noted in *C. fasciculata* to bear tubercles in two fascicules, one at each end. "They may be smooth, nodose, anteriorly and posteriorly, or covered with scattered nodes," writes Peck (1941, p. 299), and his Figs. 18-21 show a remarkable parallel line of development to the British species, though in other characters the species are different. Another species described by Peck shows affinity with *C. granulosa*. In *C. compta* "the nodes are concentrated around outer parts of the valves, leaving the center free" (Peck, 1941, p. 300). The specimens are smaller than *C. granulosa*, measuring only 0.8 mm. in length, and the shape is distinct, *C. compta* tapering markedly towards the posterior. Peck suggests that "*Cypridea dunkeri* Jones . . . so closely resembles *C. compta* that they might be considered varieties of one species" (1941, p. 300). This is not the case, however, for Jones's *dunkeri* is an *Uvella* (see below, pp. 145-6). Both *C. anomala* and *C. compta* are quoted from the Draney and Lower Bear River formations, and the former from the Kootenai formation as well. *C. anomala* is abundant, *C. compta* rare. "The Kootenai overlies the Morrison in central Montana," comments Peck (p. 287), and he considers that both ostracods and charales are related more closely to those from the Purbeck of England than to the microfossils of the Morrison formation. From this he concludes "that the Morrison is Jurassic and probably older than the Purbeck." The parallel line of development in the ornament of *Cypridea* so marked in the Middle Purbeck of Europe might be considered to contribute further evidence in favour of correlating these so-called Lower Cretaceous rocks of America (the Draney, Kootenai and Lower Bear River formations) with the Purbeck-Wealden of England, even if not more definitely with the Middle Purbeck. The tendency itself warrants consideration as an evolutionary trend more widespread than has been supposed. Miss Betty Kellett is at the time of writing undertaking an investigation of the Morrison ostracods, the results of which should do much to help correlate these American deposits with their European counterparts.

Cypridea (Cypridea) propunctata sp. nov.¹

Cypridea punctata Jones, 1885, p. 337, and pl. viii, figs. 4 and 5.

? *Cypris punctata* Forbes, in Lyell, 1855, p. 297, fig. 339a.

(non *Cypris punctata* Desmarest, 1825, p. 385.

nec *Cypridea punctata* Martin, 1940.)

¹ As no type of Forbes' species *C. punctata* has survived, *propunctata* is quoted as a new species rather than a new name.

Description

Almost equivalve, selvage of the left valve overlapping that of the right. Highest at antero-dorsal angle, in anterior third. Notch strong; postero-ventral projection of the left valve conspicuous, directed towards the posterior.

Dimensions of holotype (complete carapace): length, 0.9 mm.; height, 0.7 mm.; width, 0.4 mm. Proportions of holotype—length: height: width, 1.29:1:0.57.

Both valves are punctate, the puncta being more regular in size than in the genotype. They are arranged parallel to the margin towards the periphery of the valves. (Plate 4, Figs. 1 and 2).



FIG. 22.—*Cypridea propunctata* sp. nov. Holotype. Brit. Mus. No. In.39025. Complete carapace, seen from right side. $\times 120$.

Hinge margin, contact margin and muscle scars as for genus (Fig. 17).

Types

Holotype (complete carapace): Brit. Mus. No. In 39025 (Jones's No. 34.5). For locality and horizon see below.

Paratypes: Brit. Mus. Nos. 1 1658, and In 39026, 39027.

Figured specimens

1. Jones, 1885, pl. viii, fig. 5. Brit. Mus. No. In 39026 (Jones's No. 34.20). (Postero-dorsal portion of carapace broken off).

2. Jones, 1885, pl. viii, fig. 4. Brit. Mus. No. In 39027 (Jones's No. 34, 23, not 34, 13).

3. This paper fig. 22. Holotype. Brit. Mus. No. In 39025 (Jones's No. 34, 5).

4. This paper, pl. 4, figs. 2 and 3. Brit. Mus. No. In 39175.

5. This paper, pl. 4, fig. 1. Brit. Mus. No. In 39177.

6. This paper, fig. 17a. Brit. Mus. No. In 39177; fig. 17b, Brit. Mus. No. 39176.

Remarks

The *Cypridea punctata* of all authors since 1885 has been based on Jones's figures and descriptions (1885, p. 337, pl. viii, figs. 4 and 5). Jones maintained that this species was that figured by Lyell, 1855, p. 297, fig. 339b, as *Cypris punctata* E. Forbes. However, Jones's species bears no resemblance to Lyell's figure (reproduced as fig. 23 in this paper), and moreover this *Cypris punctata* of Forbes is

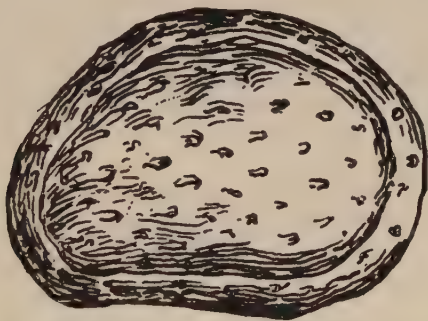


FIG. 23.—“*Cypris punctata*, E. Forbes.” A reproduction of fig. 339b of Lyell (1855). Re-drawn and enlarged.

specifically stated to be peculiar to the Lower Purbeck, from which beds no species of *Cypridea* has yet been recorded. *Cypris punctata* is again quoted as characteristic of the Lower Purbeck by Damon (1884, p. 209) in a section “measured in the cliffs by H. W. Bristow . . . the fossils named by Prof. E. Forbes.” Lyell's figure is very unsatisfactory, but in any case the name *Cypris punctata* was pre-occupied for another species (Desmarest, 1825). “*C. punctata* Forbes” is therefore a homonym and no longer stands. Of the two “varieties” included under this species by Jones in 1885, “*Cypris gibbosa* Forbes, 1855” is pre-occupied by Baird, 1838, and thus is another homonym, and *C. punctata* var. *posticalis* Jones is to be regarded as a distinct species, as described below. Therefore a new name must be found for the ostracod described by Jones under the name “*Cypridea punctata* (Forbes)”; *propunctata* is the name here proposed.

Jones figured two specimens of *C. propunctata*, both from the inside. Both can still be seen in the collection of the British Museum,

together with other specimens on the same slide. His plate viii, fig. 5, shows the inside of a broken shell. His fig. 4, which purports to show the inside of the left valve, is actually composed of three partly broken valves closely packed inside one another, thus presenting an entirely misleading appearance of marginal characters that do not exist. He made the same unfortunate choice when figuring the inside of *C. granulosa*, as noted above. There is also an error in the legend to this figure in the Explanation of Plates (Jones, 1885, p. 351), where this specimen is quoted as Jones's No. 34, 13. Actually it should have read 34, 23.

As neither of these damaged specimens would make a good choice as type, I have selected another specimen from the same slide to be holotype of *Cypridea propunctata* (Fig. 22).

Occurrence and Distribution

The locality is given as "Upper Purbeck, Durlstone Bay" by Jones on p. 351. The holotype is accompanied on Jones's slide 34 by specimens of *C. rectidorsata* subsp. nov. Therefore (although no reliable record exists as to the exact stratum in Durlston Bay, from which it was collected) the type horizon can be confidently assumed to be the lower part of the Upper Purbeck (*rectidorsata* sub-zone).

Cypridea propunctata has been reported from many horizons throughout the Upper and Middle Purbeck, but it is significant to note that whereas there is practically no variation of shape in specimens of the species from the horizon of the type, there exists a very considerable variation in specimens (identified in the past as *Cypridea punctata*) from other beds. Until now almost any *Cypridea* found in the Purbeck that is not ornamented with tubercles or spines has been loosely assigned to this species.

Cypridea (Cypridea) tuberculata (J. de C. Sowerby)

Cypris tuberculata Sowerby, 1836.

Cypridea tuberculata Anderson, 1939.

Cypridea (Cypridea) tuberculata adjuncta Jones

Cypridea tuberculata var. *adjuncta* Jones, 1885, p. 343, pl. viii, figs. 22-24.

Description

Carapace sub-rectangular, but highest at the antero-dorsal angle in the anterior third.

Dimensions of lectotype: length, 0.98 mm.; height, 0.54 mm.; width (single valve, not counting height of tubercles), 0.15 mm.; height of tubercles, 0.10 mm. Proportions—length: height: width (complete carapace less tubercles), 1.81:1:0.56.

Surface reticulate and ornamented with large protuberant

conical tubercles, arranged in a pattern related to that described by Anderson (1939) for allied sub-species.

Types

Lectotype : Brit. Mus. No. In 39016 (Jones's No. 27, 3).

Metatypes : Brit. Mus. Nos. In 39014, 39015, 39017 and 39018 (Jones's Nos. 27 : 1, 2, 4 and 5).

Figured specimens

Jones, 1885, pl. viii, figs. 22-24, lectotype (see above).

This paper, pl. 4, fig. 6 : specimen lost. Locality, Bacon Hole, field ref. No. BHC 0a. Brit. Mus. No. In 38178 is a comparable specimen (left valve) from exactly the same horizon and locality.

Occurrence

The type locality is at Bacon Hole, Mupe Bay, on the Dorset coast, where this sub-species occurs in thin-bedded limestones at the top of the Purbeck (*setina* sub-zone) and is at that horizon excessively abundant. It is also present in Upper Purbeck beds exposed in some excavations made in 1939 300 yards east-south-east of Dinton Railway Station in the Vale of Wardour (field ref. No. DSA 9).

Cypridea (Cypridea) posticalis Jones

Cypridea punctata var. *posticalis* Jones, 1885, p. 338, pl. viii, fig. 8.

Cypridea posticalis Martin, 1940, pp. 307-310, pl. 3, fig. 44, pl. 4, figs. 46, 48, 49.

This distinctive ostracod is adequately described by Jones, 1885. The majority of individuals have an outline rather less produced towards the posterior than the specimens figured by Jones and by Martin.

Sub-genus ULWELLIA Anderson

Ullwellia, Anderson, 1939.

Genotype : *U. menevensis* Anderson, 1939.

Cypridea (Ullwellia) dunkeri (Jones)

Cypridea dunkeri Jones, 1885, p. 339, pl. viii, figs. 9, 10, 17.

Not *Cypridea dunkeri* ? Martin, 1940.

Ullwellia papulata var. *poxwellensis* Anderson, 1941.

Anderson's figure and description of this species (under the name *poxwellensis*) admirably portray its characters. It is an abundant ostracod at one horizon in the *granulosa* sub-zone, when it is usually accompanied by *C. posticalis*. I do not consider it is related to *C. (U.) papulata* (Anderson), from the Swindon Purbeck beds.

Lectotype (here chosen) : Brit. Mus. No. In 39023 (Jones's No. 61A. 16). Figured Jones (1885), pl. viii, fig. 9.

Sub-genus PSEUDOCYPRIDINA Roth, emended

Pseudocypridina, Roth, 1933.

Langtonia, Anderson, 1939.

Genotype : *Pseudocypridina piedmonti* Roth, 1933.

Diagnosis : *Cypridea* with left valve the larger ; notch very slight or absent ; beak much reduced ; postero-ventral projection of left valve very slight or absent ; ornament weak or absent.

Remarks : The genus was introduced by Roth (1933) for a species in which he could detect no notch. The genotype of Anderson's genus *Langtonia* is also referable to *Pseudocypridina*. Anderson included as a diagnostic character of *Langtonia* the absence of punctuation observed in his species. It is to be noted, however, that the species *Cypridea* (*Pseudocypridina*) *piedmonti* shows a certain variation in the development of the punctuation. I have seen no individuals that are more than weakly punctate, and most are practically smooth. The trend of the sub-genus is clearly towards levigation in all characters.

My attention was first drawn to the similarity of *Pseudocypridina* and *Langtonia* by Miss Betty Kellett, who also sent some of Roth's type material for comparison with the British material. I am following her advice in quoting *Langtonia* as a synonym.

Cypridea (*Pseudocypridina*) *setina* (Anderson)

Langtonia setina Anderson, 1939, p. 305, pl. xii, fig. 7.

Cypridea (*Pseudocypridina*) *setina setina* (Anderson)

Langtonia setina Anderson, 1939, p. 305 (pars), pl. xii, fig. 7a, not 7b.

Outline of carapace semi-circular. Surface smooth.

Dimensions of lectotype (complete carapace) : length, 0.94 mm. ; height, 0.54 mm. ; width, 0.42 mm. Proportions of lectotype—length : height : width, 1.74 : 1 : 0.78.

Type and figured specimen

Lectotype, Geol. Mus. No. 60682 ; Anderson, 1939, pl. xii, fig. 7a.

Occurrence

Lectotype from No. 1 Well, Paulsgrove, Portsdown, Hampshire, 2250 to 2255 feet. In my collections it is represented from beds in Worbarrow Tout, Bacon Hole, Poxwell and Osmington Mills.

Remarks

C. (P.) setina was based by Anderson on two syntypes, both from the same well, but from samples from different (adjacent)

depths. There is a slight difference of outline between the two specimens, and field work shows that they characterise two distinct horizons. Both sub-species are widely distributed and often abundant. They provide useful stratigraphical indices, and therefore have been separated as chronological sub-species.

Cypridea (Pseudocypridina) setina rectidorsata subsp. nov.

Langtonia setina Anderson, 1939, p. 305 (pars) and pl. xii, fig. 7b, No. 7a.

Outline of carapace similar to *C. (P.) setina setina* except that the median dorsal line is straight, not curved. The dorsal outline

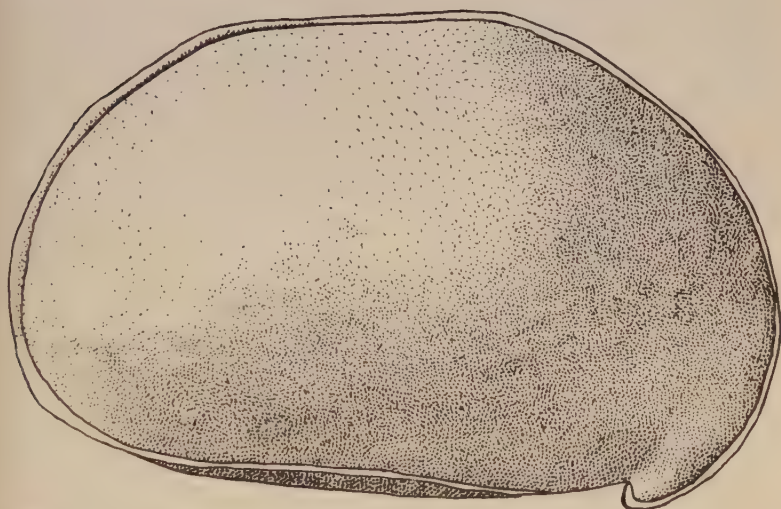


FIG. 24.—*Cypridea (Pseudocypridina) setina rectidorsata*. Holotype. Upper Purbeck (Unio Beds), Osmington Mills (OMA 22). Brit. Mus. No. In.39180. $\times 100$.

therefore shows a definite antero-dorsal angle, which is the position of greatest height.

Dimensions of holotype (complete carapace) : length, 1.05 mm. ; height, 0.68 mm. ; width, 0.50 mm. Proportions—length : height : width, 1.54 : 1 : 0.74.

Type and figured specimens

Holotype : Brit. Mus. No. In 39180. From an excavation in the "Unio Beds" (Bristow and Fisher, 1857) of the Upper Purbeck in the Osmington Mills inlier, Dorset. Field ref. No. OMA 22 ; a layer of red and green mottled clay, nine inches thick, with marly patches, containing lignite and crushed *Unio* shells. Fig. 24.

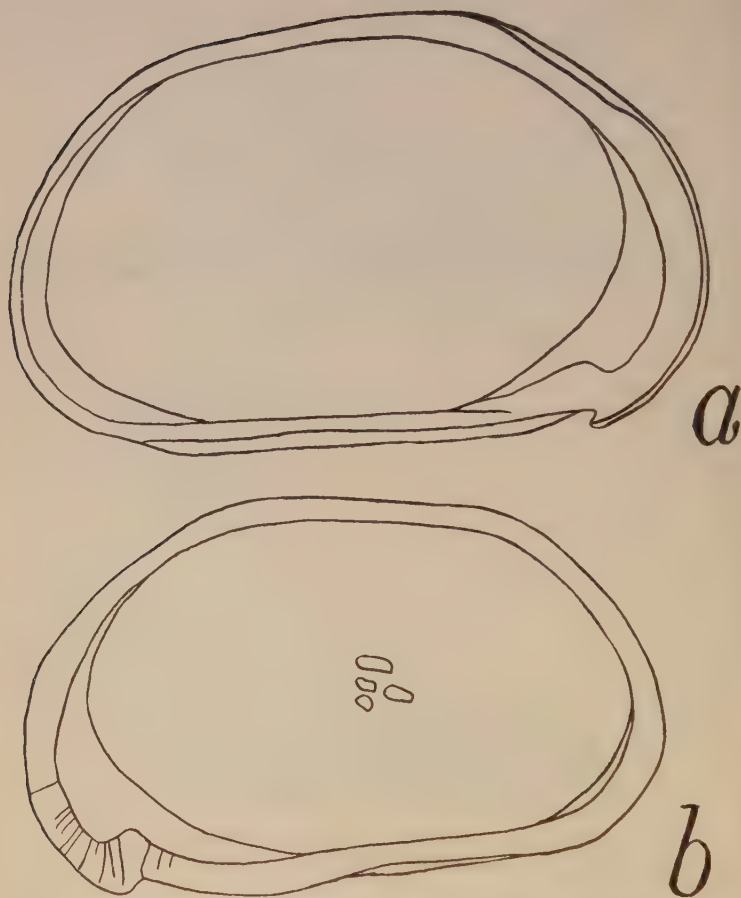


FIG 25.—*Cypridea* (*Pseudocypridina*) *setina rectidorsata*. Paratypes. (a) Left valve, Brit. Mus. No. In.39181 ; (b) Right valve, Brit. Mus. No. In.39182. Both seen from inside. $\times 90$.

Paratypes : left valve (fig. 25a), Brit. Mus. No. In 39181. Right valve (fig. 25b), Brit. Mus. No. In 39182. Locality and horizon as for holotype.

Anderson (1939), pl. xii, fig. 7b. Geol. Mus. No. 60679. No. 1 Well, Portsdown, Hants, 2245 to 2250 feet.

Remarks

In my collections this sub-species occurs in its characteristic horizon (see p. 129 above) at Durlston Bay, Worbarrow Tout, Bacon

Hole, Poxwell and Osmington Mills. The specimen figured by Anderson (1939) is reported from a well sample immediately above that containing the figured specimen of *setina setina*. They occur, therefore, in the inverse order from that shown in the field. There is no other record of the two subspecies overlapping in vertical range. The well samples were from mud flushes which, by their nature, tend to mix the micro-fauna from adjacent beds.

5. ACKNOWLEDGMENTS

Professor H. L. Hawkins and Professor F. W. Shotton have read through the manuscript at various stages of its inception and have contributed valuable criticism and advice. Mr. F. W. Anderson, in a correspondence extending over some years, has never failed to offer a stimulating challenge by his helpful criticism. Mrs. E. H. Nadeau (Miss Betty Kellett) has likewise exchanged specimens and ideas with great generosity. Mr. R. V. Melville has helped me with the collections of the Geological Survey, and Dr. J. P. Harding, Dr. H. M. Muir-Wood and Mr. T. H. Withers with those of the British Museum. To all these persons I should like to tender my gratitude.

All the illustrations are by the author.

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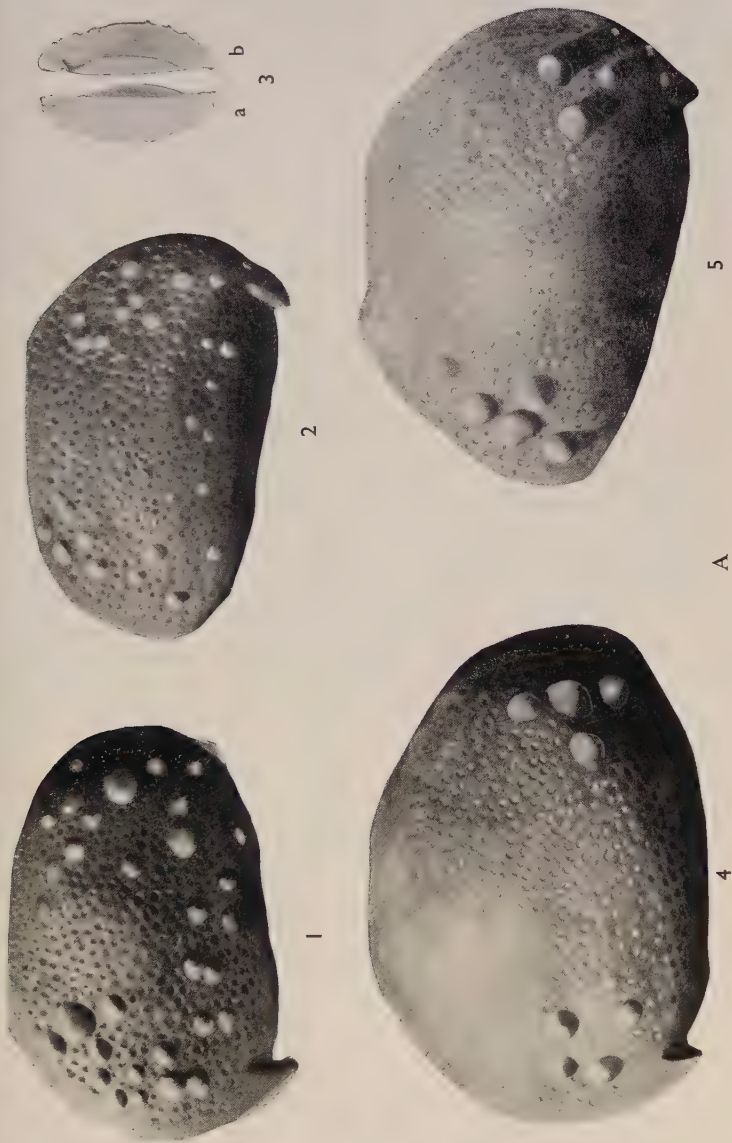
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EXPLANATION OF PLATES 3 AND 4

(Degrees of magnification are approximate).

- A.—1. *Cypridea (Cypridea) granulosa* (Sow.), left valve. Brit. Mus. No. In.39169. $\times 50$.
2. *Cypridea (Cypridea) granulosa* (Sow.), right valve. Brit. Mus. No. In.39170. $\times 50$.
3. *Cypridea (Cypridea) granulosa* (Sow.). (a) Right valve ; (b) left valve ; both viewed from below. Brit. Mus. Nos. In.39170 and 39169. $\times 20$.
4. *Cypridea (Cypridea) granulosa aff. fasciculata* (Forbes), left valve. Brit. Mus. No. In.39173. $\times 55$.
5. *Cypridea (Cypridea) granulosa aff. fasciculata* (Forbes), right valve. Brit. Mus. No. In.39174. $\times 55$.



A
The Ostracod genus *Cypridea*.



B
The Ostracod genus *Cypridea*.

- B.—1. *Cypridea* (*Cypridea*) *propunctata* sp. nov., left valve. Brit. Mus. No. In.39177. $\times 55$.
 2. *Cypridea* (*Cypridea*) *propunctata*, complete carapace, from the right side. Brit. Mus. No. In.39175. $\times 55$.
 3. *Cypridea* (*Cypridea*) *propunctata*, sp. nov., complete carapace. (a) From below; (b) from above. Brit. Mus. No. In.39175. $\times 20$.
 4. *Cypridea* (*Cypridea*) *fasciculata* (Forbes). Details of hinge structure of right valve. $\times 75$.
 5. *Cypridea* (*Cypridea*) *fasciculata* (Forbes), hinge of left valve. $\times 75$.
 6. *Cypridea* (*Cypridea*) *tuberculata adjuncta* Jones, left valve. (Specimen lost; see p. 26.) $\times 50$.

APPENDIX

A SECTION OF THE PURBECK BEDS AT POXWELL

POXWELL CUTTING (30/741834) DORSET

(From a section measured in 1936–38 with the help of Mr. Brian Mottram. Dr. W. J. Arkell kindly allowed me to compare my section with that which he measured for the *Geol. Surv. Mem.* He also identified the gastropods. Prof. T. M. Harris identified the Charophyta. The unnamed ostracods are to be described in due course by Mr. F. W. Anderson. The zonal arrangement follows that proposed by the author.)

PURBECKIAN

C. setina zone. Upper Purbeck		ft. ins.	
Subzone of <i>Cypridea rectidorsata</i>			
50.	Slipped clay, not in position, but yielding many ostracods. <i>Cypridea tuberculata</i> var., <i>C. propunctata</i> , <i>C. (Pseudocypridina) rectidorsata</i> , <i>Cyprione</i> sp., <i>Metacypris</i> sp.		
49.	Sandy bed, <i>Unio valdensis</i> , <i>Cypridea propunctata</i> , <i>C. (Pseudocypridina) rectidorsata</i> , <i>Cypridea</i> spp. nov. A and B, <i>Cyprione</i> sp. <i>Metacypris</i> sp.		6
48b.	Calcite Mudstone about	1	0
a.	Shaly marl. <i>Cypridea propunctata</i> , <i>C. (Pseudocypridina) rectidorsata</i> , <i>Cypridea</i> spp. nov. A and B, <i>Cyprione</i> sp., <i>Metacypris</i> sp. seen to		6
Gap.			
46.	Shaly marl. <i>Cypridea propunctata</i> , <i>Cypridea</i> spp. nov. C and D, <i>C. (Uwellaia)</i> sp. nov. A, <i>Cyprione</i> sp., <i>Metacypris</i> sp., " <i>Candona</i> " sp., " <i>Cypris</i> " sp., fish teeth ... about	1	0
C. granulosa zone. Middle Purbeck			
Subzone of <i>Cypridea fasciculata</i>			
45c.	Hard marlstone 1 to	2	0
b.	Shale. <i>Cypridea (Uwellaia)</i> sp. nov. A, <i>Cyprione</i> sp., <i>Metacypris</i> sp., <i>Clavator bradleyi</i> about		6
a.	Calcite mudstone about	1	0
44.	Hard crystalline limestone. <i>C. (Uwellaia)</i> sp. nov. A, fish...		6
43.	Sandy bed with rotted lamellibranchs (? <i>Corbula</i>), <i>C. (Uwellaia)</i> ? sp. nov. A, fish teeth		7
42.	Rotted lamellibranchs (reduced to a white, powdery marl), clay and beef. Ostracods indet about	3	0

		ft.	ins.
41.	Corbula limestone. <i>Cypridea fasciculata</i> , <i>C. (Ullwellia)</i> sp. nov. A, " <i>Candona</i> " <i>bononiensis</i> , fish teeth...		8
40.	Beef and clay. <i>Planorbis fisheri</i> , <i>Hydrobia chopardiana</i> , <i>C. (Ullwellia) dunkeri</i> , <i>C. (Pseudocypridina)</i> sp. nov. A, <i>Cyprione</i> sp., <i>Metacypris</i> sp., " <i>Cypris</i> " sp., " <i>Candona</i> " <i>bononiensis</i> , ostracod gen. et sp. nov., <i>Clavator grovesi</i> , <i>Perimneste horrida</i> ...	6	0
39.	Perished shells and beef. Squashed <i>Cypridea</i> sp., fish teeth ...	3	0
38.	Clay and beef. Fish teeth. Branched hollow tubes about	12	0
37.	Shell limestone ...		6
36.	Marl and beef. <i>Hydrobia chopardiana</i> , ? " <i>Candona</i> " sp., <i>Acrodes ornatus</i> ?, <i>Lepidotus</i> sp., <i>Hybodus parridensis</i> ? about	1	6
35.	Compact, marly limestone. Ostracods indet ...	1	3
34.	Shell limestone. <i>Macrodentina textilis</i> , " <i>Candona</i> " <i>ansata</i>		1
33.	Clay, marl and beef. <i>Valvata helicoides</i> , <i>Cypridea</i> sp., <i>Macrodentina textilis</i> , fish teeth ...	1	0
32b.	Thin, earthy shell limestone ...		2
a.	Ferruginous clay. <i>Macrodentina textilis</i> , fish teeth 0 to		1
31.	Limestone. <i>Neomiodon</i> and broken shells, " <i>Candona</i> " <i>ansata</i> , abundant fish teeth ...	1	0
30.	Limestone and marlstone. <i>Macrocypris</i> ? ...		9
29.	Perished shells, with much beef. <i>Physa bristovii</i> , ? <i>Valvata</i> , <i>Cypridea posticalis</i> , <i>Cypridea</i> sp., <i>Metacypris</i> sp., fish teeth, <i>Clavator reidi</i> ?, <i>C. grovesi</i> ...	1	0
28.	Mottled clays. <i>Cypridea</i> sp. indet ...	1	6
27.	White marl and beef. Ostracod indet ...		4
26e.	Sand and sandy clay. Fish teeth ...		5
d.	Sandstone ...		2
c.	Gritty limestone. Lamellibranch casts (? <i>Corbula</i>), <i>Cypridea</i> sp. ...		11
b.	White argillaceous sand. <i>Valvata helicoides</i> ?, fish teeth about		3
a.	Reddish, sandy clay. Fish teeth ...		6
25.	Shell limestone. <i>Cypridea fasciculata</i> , <i>C. cf. propunctata</i> ...		9
24.	Beef and clay. <i>Cypridea posticalis</i> , ? " <i>Candona</i> " sp., <i>Clavator cf. reidi</i>		
Gap			
22.	Clay, with thick layers and thin seams of perished shells. <i>Planorbis fisheri</i> , <i>Valvata helicoides</i> , <i>Hydrobia chopardiana</i> , <i>Cypridea</i> sp. nov. E, <i>C. (Ullwellia) dunkeri</i> , <i>Metacypris</i> sp., fish teeth, <i>Clavator grovesi</i> , <i>Perimneste horrida</i> , wood		
21.	Marl. <i>Ostrea distorta</i> , <i>Cypridea fasciculata</i> ...	1	0
20.	CINDER BED. <i>Ostrea distorta</i> , more abundant at top	1	7
19.	Limestone with <i>Ostrea distorta</i> ...	1	3
18c.	Clay. <i>Cypridea fasciculata</i> . Fish teeth ...		1
b.	Thin marl and limestone. <i>Ostrea distorta</i> , <i>Cypridea fasciculata</i> ...		5
a.	Thin bedded limestone with finely broken shells. <i>Cypridea fasciculata</i> ...		8
17.	Marly shale. <i>Valvata helicoides</i> , <i>Planorbis fisheri</i> , <i>Hydrobia chopardiana</i> , <i>Viviparus cariniferus</i> , <i>Physa bristovii</i> , <i>Cypridea fasciculata</i> , <i>Metacypris</i> sp., " <i>Candona</i> " <i>bononiensis</i> , <i>Clavator grovesi</i> , <i>Perimneste horrida</i> ...		5
16c.	Shell limestone. <i>Cypridea fasciculata</i> , <i>Metacypris verrucosa</i> 0 to		1
b.	Marl ...		4

ft. ins.

- a. Softer marl. *Hydrobia chopardiana*, *Planorbis fisheri*, *Valvata helicoides*, *Viviparus subangulatus*, *Ellobium jaccardi*, *Cypridea* cf. *propunctata*, *C.* cf. *valdensis*, *Metacypris forbesi*, "*Candona*" *bononiensis*, *Clavator grovesi*, *Perimneste horrida* about 6

Subzone of *Cypridea granulosa* (sensu stricto)

15. "The Biscuit Bed." Calcite mudstone and chert, the top of which is piped by funnel shaped inclusions of marl, thus weathering to a characteristic "biscuit like" surface (seen also, e.g., at Durdle Door). *Viviparus subangulatus*, *Planorbis fisheri*, *Valvata helicoides*, *Physa bristovii*, *Hydrobia chopardiana*, *Neomiodon* sp., and other lamellibranchs, *Cypridea* cf. *propunctata*, *C.* sp. nov. E, *C.* cf. *valdensis*, *C.* (*Uwellia*) *dunkeri*?, *Cyprione* sp., *Metacypris forbesi*, *M. verrucosa*, *Clavator reidi*, *C. grovesi* 2 1
14. Clay and perished shells. *Cypridea* cf. *valdensis*, *C.* (*Uwellia*) *dunkeri*, *Metacypris forbesi*, *M. verrucosa*, *Clavator reidi*, *Perimneste horrida* 4
13. Blue-hearted calcite-mudstone. *Cypridea* cf. *propunctata*, *C.* cf. *valdensis*, *C.* (*Uwellia*) *dunkeri*, *Metacypris forbesi*, *M. verrucosa*, *Clavator grovesi*, *C. reidi* 1 2
- 12b. Soft, shaly marl, with a layer of lignite consisting of small branched twigs. *Cypridea posticalis*, *C.* (*Uwellia*) *dunkeri*, *Metacypris verrucosa*, all in great abundance, fish scales ... 1 6
- a. Marlstone. *Cypridea granulosa* (rare), *C. posticalis*, *C.* (*Uwellia*) *dunkeri*, fish scales... .. 1 0
- 11b. Clay. *Cypridea granulosa* (rare) 1 0
- a. Marl. *Hydrobia chopardiana*, *Metacypris* sp., *Clavator grovesi* 2
10. Blue-hearted calcite-mudstone, shelly at base. *Hydrobia chopardiana*, *Cypridea granulosa* (common)... .. 1 11
9. Soft marl and clay 1 4
8. Blue-hearted calcite mudstone, shelly at base. *Cypridea granulosa* (abundant) 1 1
- 7b. The *Cypridea* Bed. Limestone almost entirely composed of *Cypridea granulosa* 4
- a. Shelly limestone. *Neomiodon* casts. *Cypridea granulosa* about 5
6. Clay, marly at top 9
5. Irregular marl 1 to 6
4. Root Bed. Marlstone piped by slender root-like markings 1 5
3. Marly clay. *Cypridea granulosa* (rare) about 1 0

C. *purbeckensis* zone. Lower Purbeck

2. Limestone. Ostracods... .. 11
1. Marls, calcite mudstone and marlstone, seen intermittently for about 6 0

NOTES.—1. The upper beds (38–50) were intersected at a very acute angle to the strike, and the thicknesses should only be regarded as approximate.

2. The code letters in the author's collections, some of which have been quoted elsewhere, are prefixed by the letters "PC" and are numbered from the top downwards. They can be correlated with the above bed numbers by subtracting from 50.

A NEW SPECIES OF POLYZOAN FROM THE ENGLISH LOWER CRETACEOUS

By LESLIE J. PITT, F.G.S.

[Received 25th November, 1948.]

A NEW species of *Tholopora*, which was discovered during investigations into the Polyzoan fauna of the Lower Greensand of Faringdon, Berkshire, is described below. In order to clear up confusion *Tholopora virgulosa* (Gregory) has been re-defined after examining the holotype, which is figured for the first time.

I have to thank Major Royds, of Coxwell Lodge, Faringdon, for so readily granting permission to collect from the now disused pit in his grounds ; the Keeper of the Department of Geology, British Museum (Natural History), for permission to examine specimens in his charge ; Dr. H. Dighton Thomas, for his continued help and encouragement in my studies ; Prof. H. L. Hawkins, F.R.S., for the loan of material from the L. Treacher Collection in the University of Reading ; and Mr. S. A. Tibbitts and Mr. W. H. T. Tams for the excellent photographs.

FAMILY RADIOPORIDAE GENUS *THOLOPORA* Gregory

Tholopora thomasi sp. nov.

Plate 5, Figs. 1a, b ; Plate 6

1926. *Tholopora virgulosa* (Gregory) : Canu & Bassler, p. 63, pl. 20, fig. 1*
(non *Domopora virgulosa* Gregory, 1909, p. 66).

Material and horizon.—The holotype and three paratypes, all from the Lower Greensand (Aptian). The holotype, British Museum (Natural History), D.37291, and two of the paratypes, D.37292-3, are from the Little Coxwell Pit, Faringdon, Berkshire ; the third paratype, which is in the L. Treacher Collection, Reading University, is from Faringdon, but otherwise unlocalised.

Diagnosis.—*Tholopora* with the zoarium commencing as a short thick stem expanding to an irregular head from which arise short columns consisting of superimposed hemispherical sub-colonies. The well-marked vertical rows of apertures are separated essentially by a single row of mesopores. There are between 20 and 50 vertical rows of apertures in each sub-colony.

Dimensions :

	Holotype	Paratype in Treacher Coll.
Height of zoarium	12 mm.	11 mm.
Diameter of zoarium	14 mm.	17 mm. x 19 mm.
Height of sub-colonies	2-3 mm.	2-2.5 mm.

* For list of References see p. 156.

	Holotype	Paratype in Treacher Coll.
Diameter of „	3.5-4 mm.	3-4 mm.
„ „ apertures	0.25 mm.	} too worn for accurate measurement
„ „ mesopores	0.1 mm.	

Remarks.—The zone of growth is an area of crowded zooecia. This passes into the characteristic vertical series of apertures. Just before a column bifurcates the diverging lines of apertures give a chevron effect (Plate 6). There is a marked constriction between the hemispherical sub-colonies which is well shown in the holotype and in the paratype from the Treacher Collection. The other paratypes are broken-off columns of capping sub-colonies.

This species was well figured by Canu & Bassler (1926, p. 63, pl. 20, fig. 1), who described it as *Tholopora virgulosa* (Gregory). It differs from that species (*v. inf.*), however, in the very marked linear arrangement of the apertures and the linear arrangement of the mesopores between them. Also, the apertures are larger and much less crowded. The confusion appears to be due to Gregory's interpretation of Goldfuss's poor figure of *Ceripora stellata* (1826, p. 39 *pars*; 1829, p. 85 *pars*, pl. 30, fig. 12a, b), which is *T. virgulosa* (Gregory).

Tholopora virgulosa (Gregory)

Plate 5, Figs. 2a, b

1909. *Domopora virgulosa* Gregory, p. 66.

1909a. *Tholopora virgulosa* (Gregory) Gregory, p. 277 (*cum syn.*).

Non 1926. *Tholopora virgulosa* (Gregory) : Canu & Bassler, p. 63, pl. 20, fig. 1
(=*T. thomasi* sp. nov.).

Material and horizon.—The holotype, British Museum (Natural History), D.11833, from the [? Cenomanian], "Upper Greensand" of Warminster, Wiltshire (Cunnington Collection).

Diagnosis.—*Tholopora* with the zoarium consisting of a broad base from which arise numerous sub-colonies, capped in turn by other sub-colonies, the vertical series of apertures somewhat ill-defined and separated by irregularly arranged mesopores. The separation of the sub-colonies causes annular constrictions on the columns.

Dimensions : Height of zoarium	27 mm.
Width „ „	33 mm.
Diameter of sub-colonies	3-6 mm.
„ „ apertures	0.2 mm.
„ „ mesopores	0.1 mm.

Remarks.—The zoarium of the holotype appears tuberous as the columns of capping sub-colonies are short. The zone of growth is an area of closely packed zooecia.

Gregory only mentions this species from the Cenomanian, but there is also a specimen from the Lower Greensand of Faringdon in the Treacher Collection.

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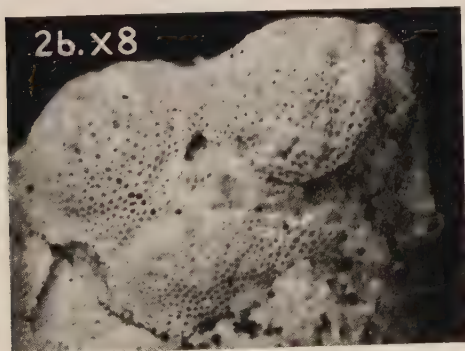
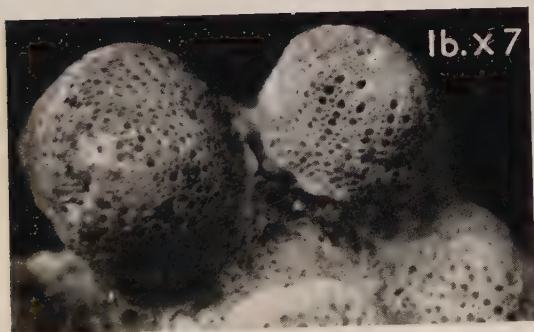
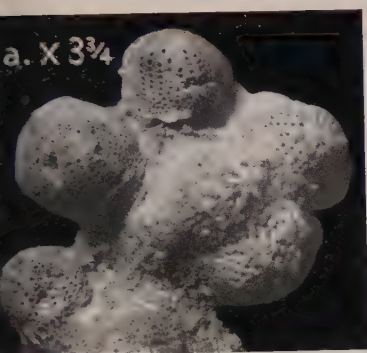
EXPLANATION OF PLATES 5 AND 6

PLATE 5

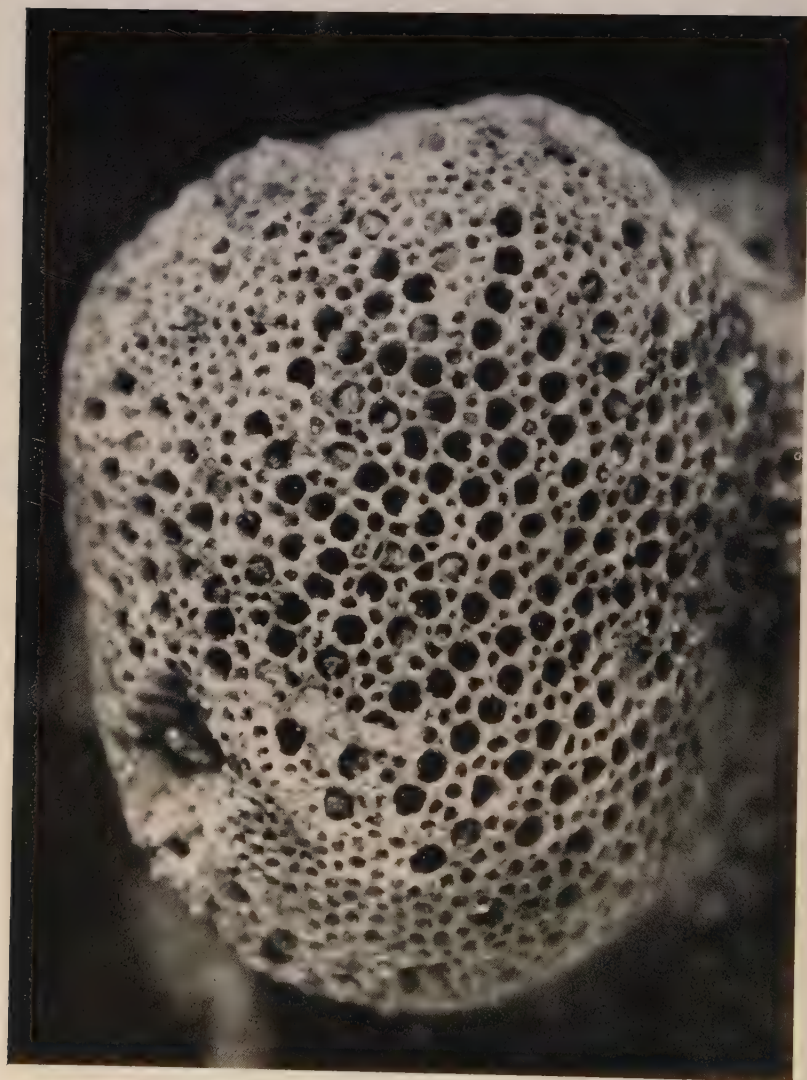
- 1A. *Tholopora thomasi* sp. nov. Holotype, British Museum (Natural History), D.37291, x $3\frac{1}{2}$. Aptian, Lower Greensand, Little Coxwell Pit, Faringdon, Berkshire. [Photo : L. J. Pitt.]
- 1B. *Tholopora thomasi* sp. nov. Part of the holotype, x 7. [Photo : W. H. T. Tams.]
- 2A. *Tholopora virgulosa* (Gregory). Holotype, British Museum (Natural History), D.11833, x 2. [? Cenomanian], "Upper Greensand," Warminster, Wiltshire. [Photo : W. H. T. Tams.]
- 2B. *Tholopora virgulosa* (Gregory). Part of the holotype, x 8. [Photo : W. H. T. Tams.]

PLATE 6

- Tholopora thomasi* sp. nov. Holotype, British Museum (Natural History), D.37291, x 24. Top view of a sub-colony about to bifurcate, showing the chevron effect produced by the diverging lines of apertures. [Photo : S. A. Tibbitts.]



1a and 1b. *Tholopora thomasi* sp. nov.
2a and 2b. *Tholopora virgulosa* (Gregory).



[Photo by S. A. Tibbitts.]

20

Thalysidites sp. nov.

HENRY STOPES

By the late A. S. KENNARD

[Mr. A. S. Kennard, the first recipient of the Stopes Medal, prepared an account of the life and geological work of Henry Stopes which was to have been given as a lecture to the Association in July, 1948, but Mr. Kennard died shortly before the date fixed for the meeting. The full typescript of his account was submitted by him to Henry Stopes's daughter, our honorary member, Dr. Marie Stopes, who had assisted him by providing family documents, etc., and, with her approval and that of Kennard's executor, has been given to the Association. It contains much material of great general interest and has therefore been placed among the Association's archives ; it can be consulted on application to the Secretary.

The Council, however, feels that it is desirable that the following brief account of the life and geological work of the pioneer geologist commemorated by the Association's only medal, based on our former President's last work, should be published in the *Proceedings*.]

HENRY STOPES, third son of Christopher and Maria Stopes, was born at Colchester on 17th February, 1852, and died at Swanscombe 5th December, 1902. The family were Quakers, but owned the Eagle Brewery in Colchester, Henry becoming a partner with his father in 1872. He specialised in engineering, and in 1880 established the business of Henry Stopes & Co., Brewers' Engineers ; he also collected an unique library dealing with every branch of brewing and allied subjects. In 1879 he married Charlotte, eldest daughter of James Carmichael, a well-known artist ; she was for many years a leading Shakespearian scholar. They had two daughters, Dr. Marie Carmichael Stopes, now an honorary member of the Geologists' Association, and Winifred Graham Stopes, who died in 1925. In 1892 he went to the Manor House, Swanscombe, and it is there that the work, for which his name will survive for ever as a Pleistocene geologist and a prehistorian, was done.

Henry Stopes had manifested an interest in geology from the age of eight, when, it is recorded, he was whipped at school for taking a fossil to bed with him. His interest survived and grew ; he made an important collection of Crag fossils, now in the museum of the Essex Field Club at Stratford. From 1873 to 1876 the Geological Survey was working in the Colchester district, and Stopes got to know W. Whitaker, Horace B. Woodward and W. H. Dalton, the last of whom became his life-long friend. As a result he became a Fellow of the Geological Society in 1874.

He was a regular attendant at meetings of the British Association, and frequently read papers, the subjects indicating the width of his interests : they include the first palæoliths recorded from Egypt and from Palestine, minerals and ores from the mines of Laurion, near Athens, and, in 1881, on "Traces of Man from the Crag." The last contains a description of the famous *Glycymeris pectunculus*

shell carved with a crude representation of a human face, supposedly human workmanship of the Crag period. In 1913 a special committee of the Prehistoric Society of East Anglia pronounced in its favour (*Proceedings*, vol. 1, pp. 323-32, Plate 73), but not all geologists accept it; the specimen is preserved by Dr. Marie Stopes.

Henry Stopes's first service to this Association was in March, 1896, when he and F. C. J. Spurrell were directors of an excursion to Swanscombe and Galley Hill, though the report (vol. 14, pp. 305-6) was by E. T. Newton, then president. Mr. and Mrs. Stopes entertained the party to tea. In May, 1901, the Association again visited Swanscombe, mainly to inspect the famous but short-lived exposure of the shell-bed opposite the Ingress Arms. The report is by the directors, A. S. Kennard and A. E. Salter, but in the account which is here condensed Kennard says: "I wrote the report, but Stopes was the real director and we willingly relinquished our nominal positions to him, for he knew far more about the district." The main object was to collect the extinct mollusca, of the greatest value in dating and correlating the Pleistocene—*Unio littoralis* and the *Neritina*, first recorded by Stopes in the previous year as *N. fluviatilis*, now known as *Theodoxus cantianus* Kennard and B. B. Woodward.

Kennard's lecture then gives a long account of the work at Swanscombe, based on his own recollections of collaborating with Stopes and including many unpublished notes on exact sites, the finding of important specimens and their present whereabouts: some years after Stopes's death the bulk of his unique collection was bought by the National Museum of Wales and is now at Cardiff. That Swanscombe has become a *locus classicus* in the study of "Prehistoric Man and his Geological Environment" is largely due to Henry Stopes, for a full account of whose life and work reference must be made to Kennard's typescript; we can here only conclude with the annotated bibliography appended thereto.

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NOTE :—The above account has been written by C. E. N. Bromehead, based on A. S. Kennard's manuscript.

NOTE ON A POSSIBLE ORIGIN OF THE ALPS

By A. J. BULL.

[Received 9th March, 1944]

[Read 31st March, 1944]

SUMMARY—The nappes which build the Alps consist of Mesozoic sediments together with portions of the Palaeozoic floor on which they were deposited. It is presumed that by changes in the infra-plutonic layer of Fennoscandia the southern sediments were raised to slide by gravity northwards. Later the whole arc of the Alps was raised isostatically.

THE Alps in essence consist of nappes which have been placed upon a platform and then raised to considerable heights. These nappes are sheets of rock consisting of sediments together with the older crystalline on which the sediments were deposited that have been brought from the south and piled on each other or against granite massifs in extreme complexity. The general disposition of the groups of nappes and of the granite massifs is arcuate.

There are in the main and particularly in the west three series of nappes, the Helvetic Nappes, the Pennine Nappes and the Pre-Alps.

The Helvetic Nappes form the northern border of the Alps (except where the Pre-Alps project beyond them), and their sediments are regarded as being those of an epicontinental sea. The Pennine Nappes to the south of these in the Pennine Alps and the Ticino are also marine sediments, which have been almost completely metamorphosed to Schistes Lustrés or Bündnerschiefer sparkling with mica; but in a few places fossils have been recognised, so that the sediments are known to be Mesozoic. There are in these Alps three Palaeozoic "cores" of nappes called the Grand St. Bernard Nappe, the Monte Rosa Nappe and the Dent Blanche Nappe, but the sediments that once rested on them have been so metamorphosed that none can be related to its original foundation. The complex Pre-Alps consist partly of sediments laid down further from a coast-line than those of the Helvetic and Pennine Nappes, and they appear to have travelled over these two series of nappes from the south to their present positions.

While the structures are complex, there is in the Helvetic and in the Eastern Pennine Nappes a constant repetition of strata, which indicates a community of origin within each series. The beds involved are Trias, Rhaetic, Lias and Jurassic often with some Tertiary. In many cases as in the Pennine Alps these sedimentaries are metamorphosed to Schistes Lustrés; but occasionally they contain sufficient fossils for their ages to be determined, or like the Triassic Dolomite in the Eastern Swiss Alps they can be traced by a

distinctive lithology. The surface upon which all these nappes have been placed is a Hercynian peneplain, the higher parts or culminations of which are often granite massifs, while the lower parts are covered with Mesozoic sediments. These latter together with the granite massifs are the autochthone, that is rocks in or near their original positions ; or if they have moved some little distance from their place of origin, they are called parautochthone. Therefore there may be Mesozoic sediments as nappes resting on Mesozoic sediments as autochthone.

It would appear that the nappes came against the granite massifs with great force, for in addition to widespread Bündnerschiefer the Mesozoic sediments on the south side of the Gotthard Massif are metamorphosed to biotite rocks, garnet schists, etc., which suggests the application of very great pressure.

Some of the granite massifs have moved and crushed the sediments that had been laid down between them. There is the long narrow band of partly metamorphosed sediments squeezed between the Gotthard Massif and the Aar Massif near Andermatt, and again in France the Trias and Lias deposited between the Mont Blanc Massif and the Aiguilles Rouge Massif are folded into the narrow Chamonix zone.

Thus it is seen that the nappes of which the Alps are built consist of sediments of Mesozoic and Tertiary ages together with the crystalline Palaeozoic floor on which they were deposited. There are therefore two movements of which an explanation is required. First, sheet after sheet of the outer crust of the earth has been raised from below sea-level and placed upon the land to the north in an arcuate form, and secondly this arc has been raised to form the present mountain range.

The most probable force that could transfer a great expanse of sedimentary deposits piecemeal considerable distances is gravity, and this requires that the earth's surface to the south should have been elevated in order that sliding could take place. The idea of rocks sliding under gravity is by no means a new one ; although its importance has been insisted upon by some geologists from time to time, and it was recognised by Schardt in 1898 as the force which moved the Pre-Alps, the conception has tended to pass out of geological literature. The wide use of the words "thrust" and "thrust-plane" suggests to many people that some force outside the thing itself has been applied to the "thrust mass" to push it along the "thrust plane," and this language has been used without any suggestion as to what such a force might be. The non-committal word "slide" used by Sir Edward Bailey in 1910 is often more appropriate. In the Alps the movements have extended over a considerable time, so that material from the earlier nappes has been incorporated in the later ones.

Given the structures outlined above, it is of interest to consider

by what processes they could have been produced. The materials of which the nappes are built with their widespread marine sediments require that there should have been stable conditions for a long time with heavy rocks underlying the sea floor. The thick sial mass of Africa lay to the south ; and, as Prof. Joly [4]* pointed out, this would blanket the heat from radioactive materials in and below the crust, until the more basic rocks softened and moved outward in slow convection currents.

An important conception, which may be introduced here, is that of Sir Lewis L. Fermor's *Infra Plutonic Zone* [1] [2]. According to this conception the basaltic layer of the earth's crust, which underlies the lighter sial of the continents and forms a large part of the floor of the oceans, will produce basalt when it is extruded as lava flows on the earth's surface ; when, however, deeper parts of this layer crystallise, the rock resulting will be the plutonic phase gabbro. Still deeper in the basaltic layer the increasing pressure will favour the formation of denser minerals, and so at a depth which has been estimated at 37 to 60 km. [2, p. 61] the rock will pass into an eclogite with dense garnets. This latter shell is Fermor's *infra-plutonic layer*, which on reduction of pressure or raising of temperature may change from an eclogite to a gabbro with an increase in volume that may amount to as much as 15 per cent.

Returning to the idea of a convection current of hot material coming out from under Africa, this could stimulate the change from eclogite to gabbro in the *infra-plutonic layer*, and the consequent increase in volume would provide the mechanism for raising the sea floor so that portions of it could slide northwards. The first nappes to slide would be those of the sediments bordering Africa, and these would build up the *Helvetic Nappes*. As the high parts advanced northwards, so deposits farther from land would slide out, forming the *Pennine Nappes* ; and lastly sediments still farther from land would be raised and tipped over the existing nappes to form the bulk of the *Pre-Alps*.

The *Hercynian peneplain* upon which the nappes came to rest was presumably a land of low relief much of it below sea-level, and this together with the jumbled mass of nappes needs some mechanism to raise the whole to their present altitudes. If one imagines that the convection current of hot material was chiefly basic and pushed any light material together with the recently formed gabbro before it, then it is possible for this to be carried forward in an arc and to come to rest under the rocks of the *Hercynian peneplain* with its mass of nappes and so buoy it all up, for it must be remembered that the *autochthone* now forming the base of many mountains has itself been raised.

In this way too the nappes of the southern border of the folded mass would be pressed in under it by the current, which would

* For list of References, see p. 164.

account for the vertical nappes of the Zone of Roots and the *pli en retour* of the Mischabel, etc.

One of the most striking features of the Swiss Alps is the concordance of summit heights. To look over the snow peaks from some view-point as the Jungfraujoch or the Weissfluh is to receive the impression that they all rise up to a plane, as if the valleys below had been carved out of a high level peneplain. From the history of the Alps one knows that this is impossible. Prof. A. Heim has suggested [3] that it may be the result of interplay between isostatic adjustment and denudation. One is tempted to imagine that the cushion system of Sir Lewis Fermor's infra-plutonic layer, expanding as the pressure is relieved by denudation, may be playing the essential part in this matter.

In conclusion I wish to express my very great admiration for the manner in which the Swiss geologists have unravelled the complex tectonics of their beautiful country. It is an achievement of the highest order.

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THE DENUDATION CHRONOLOGY OF THE DIP-SLOPE OF THE SOUTH DOWNS

By B. W. SPARKS, B.A.

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[Read 1st July, 1949]

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SUMMARY—Although much is already known of the denudation chronology of the South Downs, detailed surveying of the dip-slope reveals the existence of a number of closely-spaced marine platforms, which are intermediate in age between the early Pliocene bench (650–550 feet O.D.) and the Goodwood raised beach (130–80 feet O.D.). A careful examination of the distribution of the platform fragments shows that in certain situations they must be of sub-aerial origin and related to the development of streams in the area. Thus, the river Adur is shown to have migrated eastwards since the early Pliocene, and it is suggested from certain evidence that the Ouse once reached the sea via the mouth of the Cuckmere, its present outlet being of comparatively recent origin. The major longitudinal valleys of the South Downs, i.e., the upper Lavant and the Lewes Winterbourne were clearly in existence by the 475-foot stage, which is the first clearly-defined stillstand in the regression of the sea from the early Pliocene level. The discontinuous secondary escarpment is examined in some detail and it is suggested that it was originally formed by the action of scarp-foot subsequent streams, which were later disrupted. Certain convergent dry valley patterns can be demonstrated to coincide in position with embayments of the shorelines discussed and are thus readily explicable. Finally the debated question of the origin of dry valleys is reviewed and it is concluded that there are no real objections to the hypothesis that they are former river valleys, which have been abandoned as the level of the water-table in the Chalk fell.

A detailed summary of the evidence for each platform is included as an appendix.

1. INTRODUCTION

STRUCTURALLY, the South Downs are composed of a sheet of Chalk tilted towards the south and corrugated by typically short, discontinuous, arcuate and asymmetric mid-Tertiary folds.

These folds, shown in Fig. 26, which is based upon a map published by Wooldridge and Linton [33*] and the descriptions by Clement Reid [25, 26], Osborne White [29, 30], Gaster [14] and Reeves [23], are reflected in various relief features, notably the manner in which the escarpments are subject to marked deflections and in certain longitudinal valleys. The major longitudinal valleys are those of the upper Lavant, which follows the axis of the Dean Valley anticline and is an example of inverted relief, and the Lewes Winterbourne, which, coinciding with the Mount Caburn syncline, is an example of normal relief. The general southerly dip is responsible for the two north-facing escarpments: the main escarpment, which owes its existence to a capping of the harder, lower layers of the Upper Chalk (the Echinoid Chalk), and the secondary escarpment, a discontinuous feature found half-way down the dip-slope and developed in the higher layers of the Upper Chalk (the Belemnite Chalk).

Apart from the features mentioned above, which reflect the effects of erosion upon structure, the topography is not that of a simple cuesta, but a polycyclic landscape composed of the remnants of a large number of erosional surfaces. The oldest of these is the mid-Tertiary peneplain [33, 34], which normally exceeds 700 feet O.D. in elevation and is found only in certain limited areas (Fig. 26). The edge of this peneplain was trimmed by the early Pliocene marine transgression to form a bench of limited extent, now found at an elevation of 650–500 feet O.D. From the original sediments veneering this bench, the main drainage was superimposed. The reality of the Pliocene marine planation in the South Downs rests, indeed, largely on the discordant nature of the main drainage, which transects the minor folds [33, 34]. The bench itself, a marked feature of the Chalk rim of the London Basin, has suffered considerable dissection due to the coastal position of the South Downs. The surviving relics are a number of accordant summit-levels found on the secondary escarpment and on the high ground formed of relatively-resistant *Micraster* Chalk brought up by the Dean Valley and Kingston anticlines.

The only other marine platforms previously recognised in the area are the low raised beaches, the “100-foot” or Goodwood beach found west of the Arun [10] and the “25-foot” beach found east of the Arun, the best-known exposure being at Black Rock, Brighton [28]. The “100-foot” beach, which has been dated as Boyn Hill in age on the basis of archaeological and altitudinal considerations [6, 8, 17, 22, 35], appears to be a composite feature [22], and probably corresponds with the 130-foot and 80-foot flats found in the main river gaps, notably that of the Arun, by Bull [3].

No marine platforms, dating from the period between the early Pliocene and the “100-foot” raised beach stage, have previously been recognised in the area. Some indications of the nature of

* For list of References see p. 196.

movements of base-level have been provided by Bull [4, 21], who, by careful levelling of the spurs north of the main Chalk escarpment and the adjacent lowland of Lower Cretaceous rocks, was able to demonstrate the existence of platforms at 400 feet, 320 feet and 200 feet O.D. But these platforms are certainly sub-aerial in origin and the exact base-levels to which they were graded are unknown. Moreover, although the 200-foot platform rests upon a considerable amount of evidence, the 320-foot platform is not nearly as well-developed and the 400-foot platform is based solely upon the evidence of two spur-flattenings.

In order to define more precisely the movements of base-level which occurred during this same period, the writer has carried out a detailed investigation of the dip-slope of the South Downs from Beachy Head westwards to the London-Portsmouth Road. The area thus defined is sufficiently large, some 55 miles in length and 3-7 miles in width, to ensure the establishment of a full platform sequence. The whole of this area has been surveyed carefully in order to ascertain whether recognisable platforms existed, no attempt having been made to trace a few particular platforms through the area, a method of investigation deprecated by Johnson [20].

Before defining the platforms recognised, some attention must be directed towards the methods employed.

2. THE NATURE OF THE EVIDENCE AND THE METHOD OF SURVEY

The South Downs may be classified genetically as being in a state of dissection arrested in the stage of late youth, the dip-slope having been reduced to a series of narrow sub-parallel spurs. These spurs, however, do not possess a simple slope but a step-like profile consisting of almost horizontal segments separated by markedly steeper slopes. Such flats constitute the evidence upon which the analysis of the platforms present in the South Downs is based.

A flat is defined merely as an area which visibly possesses a lower degree of slope than its surroundings, as the significance of such features must be largely deduced from a subjective assessment in the field. As the average slope of the South Downs from the crest of the main escarpment to the 150-foot contour, which marks approximately their southern limit, varies between 90 and 180 feet per mile, any visible flats must possess gradients considerably less than these.

Their elevations have been measured by means of a five-inch surveying aneroid reading to the nearest foot. As the use of this instrument has been severely criticised [20, 15 in discussion], the question of its utility in problems of the present type was investigated in the early stages of the work on the South Downs. It is hoped to publish full details of this investigation at an early date elsewhere, but the following brief summary is included here to define the accuracy with which the elevations of the flats have been surveyed.

It was found that, if the surveying was effected under suitable pressure conditions, an accuracy of $\pm$ or $-$ five feet could be obtained in short traverses, ideally of less than one hour in duration, by distributing the closing error on the assumption that pressure change had been constant. The presence of a wind exceeding 12 m.p.h. (force 4 or above on the Beaufort Scale) was found to cause additional complications preventing the use of the technique.

This degree of accuracy is quite sufficient for the survey of the South Downs flats, which are certainly not all at their original elevations, due to the operation of processes tending to produce both uniform and differential lowering. Among the former the most important are soil-creep down the sides of the spurs away from the flats, sludging during the Pleistocene when the South Downs supported local snow-caps or *névés*, and, possibly, solution. Nothing is known definitely of the rate at which Chalk topography may be uniformly lowered by solution. With the exception of solution effects beneath thin Tertiary and Quaternary sands and gravels [18, 31], arrested dissection appears to be the dominant characteristic of the Chalk lands [19, 31, 32, 34], as is evident from the preservation of platforms on the Chalk. Although uniform lowering may have occurred, it does not appear to have been considerable. On the other hand, differential lowering is the normal accompaniment of erosion: obviously some flats have been wasted more than others, some have been reduced to isolated hills, while others have, no doubt, been completely destroyed. The exact amount of lowering is, of course, unknown, but many flats appear to have been lowered by at least ten feet.

The elevations of all the flats present in the South Downs have been measured in accordance with the principles outlined above. Although it is possible that the weather may have been misjudged occasionally, the majority of the elevations recorded in the Appendix are believed to be correct to the nearest five feet. They refer to the upper and lower limits of each flat as defined by Green [16] in his survey of East Devon.

3. THE SOUTH DOWNS PLATFORMS

The flats, isolated hills and cols have been plotted in geographic order upon the accompanying height-range diagram (Fig. 27). No attempt has been made to select this material, which, as will be seen below, includes flats which are believed to be marine in origin and others which are thought to be sub-aerial. As the best evidence is provided by long flats with a small height-range, an attempt has been made to stress such flats. Whereas the vertical extent of each rectangle is proportional to the height-range of the flat depicted, the horizontal extent is proportional to the length of the flat. Thus, on the diagram, the important flats are represented by rectangles, the horizontal extents of which are large in proportion to the vertical extents.

The manner in which the flats fall into marked altitudinal groups, which remain horizontal throughout the area, clearly indicates an absence of transverse warping. Although more difficult to demonstrate, due to the narrowness of the Downs, there appears to have been a similar absence of longitudinal warping. Each platform may, therefore, be designated by the elevation of the inshore margin of the marine stage, which provides the closest approximation to the elevation of the former base-level. This method of identification is perfectly legitimate in the case of the South Downs platforms, as they are horizontal. At a later date it is hoped to extend the survey on to the Chalk dip-slopes of the Hampshire Basin, and the writer prefers to refrain from quoting the names of type-localities until the developments of the platforms elsewhere are more fully known.

As defined by the elevations of the inshore margins of the marine stages the platforms are at the following elevations. On the diagram (Fig. 27) some flats will be seen to exceed these elevations, but, as will be shown below, such flats are of sub-aerial origin and must, therefore, be expected to be higher than the corresponding marine stages.

1. The 475-foot.
2. The 430-foot.
3. The 380-foot.
4. The 345-foot.
5. The 330-foot.
6. The 290-foot.
7. The 230-foot.
8. The 180-foot.

Of these, the 475-foot and 430-foot are the most important, and the 345-foot and 180-foot the least important platforms.

Although the groups of flats representing the platforms are usually well-defined on the height-range diagram, the individuality of each platform does not rest solely upon inferences drawn from that diagram. The break of slope between each successive pair of platforms is present usually at several localities in the South Downs. Such field evidence is lacking in the case of the 230-foot and 180-foot platforms, but these differ sufficiently in altitude to eliminate any possibility of their being portions of a single platform.

(a) The Origin of the Platforms

The flats may be classified into three main groups as follows :—

1. Those occurring on the dip-slope, south of complicating relief features such as the dissected secondary escarpment and the longitudinal valleys.
2. Those found north of the secondary escarpment and in the longitudinal valleys.
3. Those present in the main river gaps.

The possibility that the platforms are structural surfaces exhumed by erosion may be discounted immediately, as it is apparent from Gaster's maps [12, 13, 14] that each platform is developed on a variety of Chalk zones. Precise details of the horizon on which each flat is developed are given in the Appendix. Thus the platforms are surfaces cut by erosion, and may, therefore, be either marine or sub-aerial in origin.

The first group of flats is undoubtedly of marine origin. The only alternative explanation would represent them as high terraces of a longitudinal stream, such as an extended Frome-Solent. Such an explanation would require the platforms to fall in elevation eastwards, but, as stated above, each platform is horizontal.

The flats included within the second group are believed to be sub-aerial in origin for a number of reasons. The general conception of movements of base-level induced by this study is one of intermittent fall. If the flats in the longitudinal valleys are to be considered marine, oscillations of sea-level, to flood those areas, must be postulated. Although such movements must have occurred during the Pleistocene with the waxing and waning of the ice-sheets, it would be necessary, in view of the distribution of flats in the South Downs, to state that an oscillation occurred at the 475-foot level, which is probably late Pliocene in age. Even had the areas been flooded, the main ocean waves must have broken against the secondary escarpment and the high ground flanking the longitudinal valleys: within the latter the fetch would have been far too limited for the formation of waves capable of marked planation. Finally, the flats in question are often higher than the marine representatives to the south: this is well marked north of the secondary escarpment behind Worthing and in the upper Lavant valley, where the 475-foot platform ranges up to 495 feet O.D., and in the valley of the Lewes Winterbourne, where the 380-foot platform rises upstream to 390 feet O.D.

The flats occurring in the main gaps are, in all probability, former terraces of the rivers occupying those gaps.

(b) The Age of the Platforms

No absolute date can be assigned to any of the South Downs platforms. That they are each younger than the platform above can be demonstrated quite easily. If a lower platform is older than a higher one, it would probably have been destroyed during the formation of the latter, especially as the normal height difference between the South Downs platforms is only 50 feet. In addition, a higher, younger platform must occur everywhere above a lower, older platform, unless large lithological differences or complete shelter from destructive waves have locally prevented its formation. The necessarily large lithological differences are not found in the Chalk, neither do the shorelines, with one or two exceptions, offer any

embayments such as might be expected to have provided complete shelter. Furthermore, as each platform can be shown either to cut out the next higher one to rest against the next platform but one in altitude, or to overrun several higher platforms in certain localities, the South Downs platforms, successively lower in altitude, are considered to be successively younger.

Although it is very difficult to assess the relative duration of each stage, some indications may be obtained from the following considerations. At each fall of base-level, assumed to be 50 feet, the shoreline probably migrated approximately two miles southwards from the Chalk on to the Tertiary rocks (from position A to position B on Fig. 28). During the succeeding stillstand, the shoreline was pushed northwards under wave-attack, rapidly across the non-resistant Tertiary rocks (positions B1, B2 and B3), but much more slowly when it reached the Chalk (position B4). If a regional dip of 1° – 2° be assumed for the Tertiary base, each shoreline must have

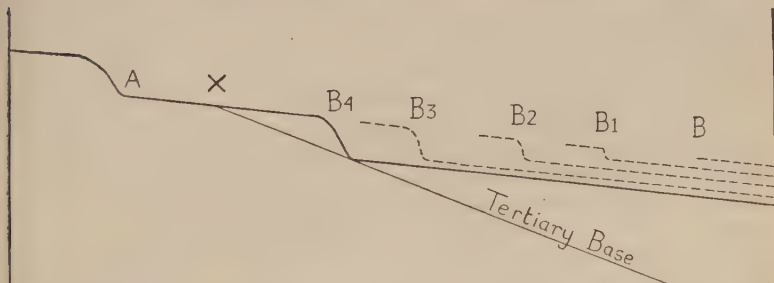


FIG. 28.—DISPLACEMENT OF SHORELINE DURING AND AFTER A FALL IN BASE-LEVEL.

passed on to the Chalk (B4) approximately one quarter to one half of a mile south of the position at which the Chalk had been encountered by the previous shoreline (X). Thus, if any stillstand had been of much greater length than the one preceding, the resulting platform must have overrun the platform above. The very fact that the South Downs platforms exist suggests that the periods of stillstand were progressively shorter. There are two exceptions to this generalisation: the 345-foot platform represents only a minor stillstand, as it has been so largely overrun by the 330-foot stage; there is a suggestion that the 430-foot was a more important stillstand than the 475-foot, as the 430-foot platform has overrun the 475-foot between Brighton and Newhaven. It is true that the initiation of the longitudinal valleys of the upper Lavant and the Lewes Winterbourne during or before the 475-foot stage—a point to be discussed below—clearly suggests that the 475-foot stillstand was of considerable duration, while the lack of such developments at the 430-foot stage suggests a shorter stillstand. Such an argument

is not, however, conclusive, as, if the main structural lines were occupied by streams at an early stage, a longer stillstand at a lower elevation could not result in any new adaptations to structure.

The platforms, therefore, demonstrate that sea-level fell intermittently from the level of the Pliocene bench to the Goodwood raised beach, the periods of stillstand being of generally decreasing duration.

(c) The Composite Nature of Certain Platforms

Although the platforms described above, together with the mid-Tertiary peneplain, the Pliocene bench, the 130-foot and 80-foot terraces and the "25-foot" raised beach, mark 13 stillstands in the denudation of the area, there are indications of further complexity in the platform record. Several of the platforms described above are probably double, but, although this can be demonstrated locally, such division cannot be effected throughout the area.

The 475-foot platform includes a number of flats which occur at approximately 450 feet O.D. This elevation is too constant to admit the possibility that it represents a freak of erosion, especially as some of the 450-foot flats are little dissected.

At two places, Halnaker Park (910098)* and Patching Hill (082078), the 330-foot platform consists of two flats, the higher at approximately 330 feet O.D. and the lower at 300 feet O.D., the two being separated by a slightly but perceptibly steeper slope.

The flats assigned to the 290-foot platform tend to occur either at 290 feet or 270 feet O.D., and, although the two are not found in juxtaposition on any one spur, there is here an indication that the stage may be composite. In fact, the period represented by the 330-foot and 290-foot platforms may be regarded as one of intermittently-falling base-level, punctuated by major stillstands at the levels indicated.

The amount of evidence for the presence of each platform is so large that each flat cannot be discussed in detail here. Fuller details of the flats, such as height-range, length and probable origin, are tabulated in the Appendix.

4. VALLEY DEVELOPMENT IN THE SOUTH DOWNS

For the present discussion a division of the South Downs into four types of terrain may be made as follows :—

1. Areas where the dip-slope is complicated by longitudinal valleys following the axes of minor folds :—

(a) The area between the meridian of Brighton and the Ouse, where the synclinal Lewes Winterbourne valley dominates the topography.

* Localities defined by National Grid references may be found on Sheets 181, 182 and 183 of the 1 inch Ordnance Survey New Popular (6th) Edition.

- (b) The area between the Arun and the meridian of Chichester, in which the upper Lavant follows the axis of the Dean Valley anticline.
- 2. Areas where the continuity of the dip-slope is interrupted by a dissected secondary escarpment :—
 - (a) Between the meridian of Chichester and the London-Portsmouth Road this escarpment is well developed.
 - (b) Between the Arun and the Adur it attains a similar development.
- 3. Areas of generally simple dip-slope :—
 - (a) The Downs between the Adur and the meridian of Brighton.
 - (b) The area between the Ouse and Beachy Head.
- 4. The main river gaps.

(a) The Main River Gaps

Although flats occur along the sides of the Arun and Cuckmere gaps, they indicate little more than the polycyclic nature of the valleys, but features of greater interest are shown in the Adur and Ouse gaps.

The Adur gap is illustrated in Fig. 29, and it is immediately obvious that there are fundamental differences between the western and eastern sides of the gap. The western side preserves a considerable number of platform fragments and is dissected by dry valleys orientated towards the river ; the eastern side has no platform fragments and no dry valleys orientated towards the river. Instead, the normal north-south dry valley pattern is resumed immediately east of the Adur. These facts are consistent with the hypothesis that, since the early Pliocene, the Adur has tended to migrate towards the east. The clearest evidence of migration is found on Annington Hill, a terraced crest preserving traces of all platforms from the 430-foot to the 330-foot inclusive. The spur to the south is almost level at a little below 290 feet O.D. for a distance of some 600 yards, but rises at its eastern extremity, Coombehead Barn, to 328 feet O.D. The latter is probably an old meander-core, formed when the 290-foot Adur entrenched itself in its 330-foot valley-floor. The position of the meander is indicated by the arcuate dry valleys, Winding Bottom and Cow Bottom, their present form being due to scouring at a much later date.

The varying width of the Ouse gap (Fig. 30) is primarily a reflection of the influences of the structures crossed by the river : the northern end at Lewes is narrow, due to the fact that the Mount Caburn syncline preserves the more resistant, lower beds of the Upper Chalk near to base-level ; the expansion in the Brooks has been facilitated by the weakness of the Lower Chalk and Gault exposed in the Kingston anticline ; to the south a further constriction is due to the reappearance, south of the Kingston anticline, of the lower part of the Upper Chalk.

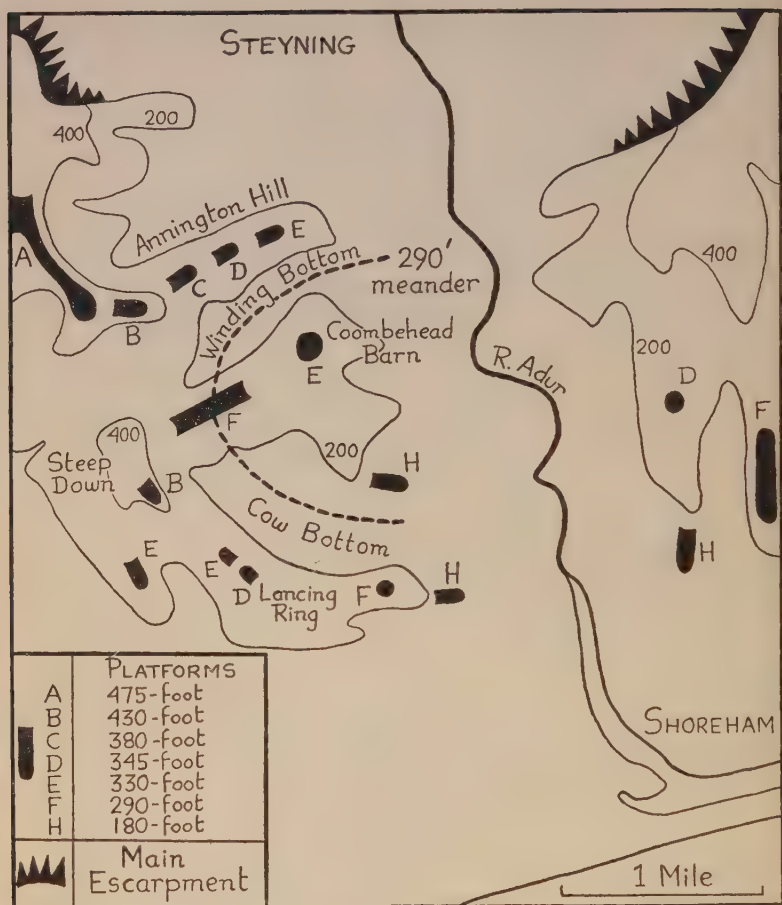


FIG. 29.—THE ADUR GAP.

There are, however, three peculiarities in the southern part of the gap :—

1. A distribution of terraces on the right bank of the river north of Newhaven, similar to the distribution on the right bank of the Adur, shows that the Ouse has tended to migrate, at least between the 380-foot and 230-foot stages, towards the north-east.

2. The "watershed" between the dry valleys draining to the Ouse and those draining directly to the sea runs diagonally out to sea between Peacehaven and Newhaven. Only the heads of southward-draining, dry valleys are exposed in the cliffs at Peacehaven, while, to the south of Newhaven, the sea has reached the

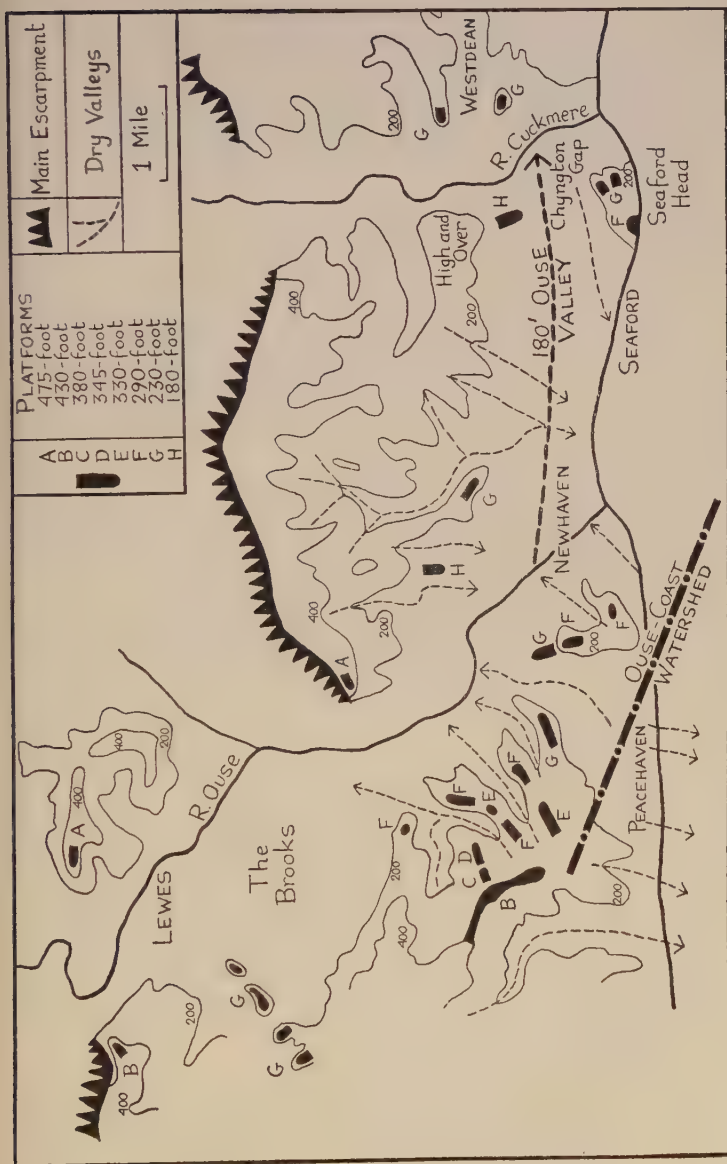


FIG. 30.—THE OUSE GAP.

head of a dry valley draining to the Ouse. Obviously the watershed dates from a time when the coastline lay well south of its present position.

3. Between Seaford Head and High and Over is a broad depression coincident with the eastward extension of the local syncline, which preserves patches of Tertiary strata at Newhaven and Seaford. In the depression, for which the name Chyngton gap is proposed, lies a remnant of the 180-foot platform at an elevation, 190–177 feet O.D., and in a position which clearly indicate a sub-aerial origin.

There appear to be three possible explanations of the Chyngton gap :—

1. It may have been formed by a small subsequent tributary of the Ouse working back along the Tertiary strata exposed in the syncline. If this were so, it is extremely difficult to see how the stream could have eroded a gap as wide as the Cuckmere valley, within half a mile of the latter, without diverting the Cuckmere, via the Chyngton gap, into the Ouse.

2. It is possible that the Cuckmere was diverted to the Ouse, but there are a number of objections to the hypothesis. The 230-foot flats north and south of Westdean (528001 and 525990) and on the eastern side of Seaford Head (503981 and 504978) show that the Cuckmere used its present outlet at that stage. If it was diverted to the Ouse at the 180-foot stage, its former outlet must have been reoccupied soon afterwards. The hypothesis does not explain the almost east–west orientation of the Ouse–coast watershed (Fig. 30).

3. It appears most likely that the Ouse joined the Cuckmere, via the Chyngton gap, at the 180-foot stage, and probably at earlier stages as well, and that its present outlet was opened up later by marine erosion. The distribution of the terraces, which betrays the tendency for the Ouse to move to the north-east, the general direction of the river itself and the dry valley pattern all support the hypothesis. Marine erosion in the area is still considerable, and the manner in which the sea has consumed its own tributary dry valleys and advanced north of the former Ouse–coast watershed indicates that marine erosion was no less important in the past, and may well have breached the Chalk in one of the interglacial periods to initiate the present outlet.

(b) The Longitudinal Valleys

The longitudinal valleys of the upper Lavant and Lewes Winterbourne dominate the landscape of the Downs between Chichester and the Arun and between Brighton and the Ouse respectively. The history of these valleys is of considerable interest in view of the suggestions, advanced by Wooldridge and Linton [34], that certain

dry valleys were formerly occupied by Pliocene consequent streams. The valleys in question are :—

1. The Chilgrove valley (Fig. 33).
2. The valley from the Cocking gap, via the lower Lavant, to Chichester (Fig. 33).
3. The valley from Stanmer Down, via North Moulsecomb, to Brighton (Fig. 32).

It may be noted immediately that two of these valleys are deflected by the folds which they cross, the Stanmer Down-Brighton valley for approximately half a mile westwards along the Mount Caburn syncline, and the Cocking-Chichester valley for approximately one mile westwards along the axis of the Dean Valley anticline. They are thus not directly comparable with the main rivers, which effect clean breaches of the folds athwart their courses. As the longitudinal valleys are intimately linked with these presumed Pliocene consequent valleys, their development throws some light on the origin of the latter.

(i) *The Lewes Winterbourne Valley (Fig. 31)*

The evolution of this, the eastern part of the valley following the Mount Caburn syncline, can be ascertained with comparative ease from the great number of platform fragments found especially on



FIG. 31.—THE TERRACES OF THE LEWES WINTERBOURNE VALLEY.

the northern side of the valley. The whole area has been exposed to sub-aerial erosion since the retreat of the sea from the Pliocene level to the 475-foot level, when the shoreline lay south of the high ground developed along the Kingston anticline, which forms the southern flank of the valley.

There is abundant evidence that the valley was in existence at the 475-foot stage, and that it migrated southwards, in accordance with the asymmetric nature of the underlying syncline, until the 230-foot stage, but the modern valley is incised into the northern part of the 230-foot valley-floor. Presumably the valley, which is essentially subsequent in type, was initiated either on Eocene rocks, an outlier of which is mapped by the Geological Survey at Falmer,

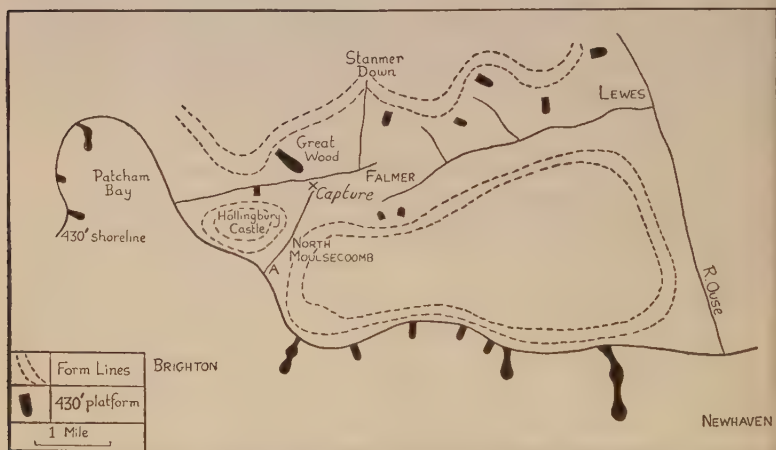


FIG. 32.—RECONSTRUCTED 430-FOOT DRAINAGE OF THE MOUNT CABURN SYNCLINE.

or on the weaker Chalk above the *M. coranguinum* zone, both of which probably outcropped, at the level of the Pliocene bench, along the Mount Caburn syncline.

Therefore, since the 475-foot stage at least, there existed an eastern outlet from Falmer along the Mount Caburn syncline. Although the evolution of the western part has been much more complex, there is one possible synclinal outlet, shown in Fig. 32. The axis of the Mount Caburn syncline passes north of Hollingbury Castle into "Patcham Bay," the significance of which will be discussed later. A dissected 475-foot flat lying north of a 430-foot col on the synclinal spur leading north from Hollingbury Castle suggests that a westward-flowing stream migrated down-dip in a manner similar to the ancestor of the Lewes Winterbourne, although the stream apparently flowed, at the 430-foot stage, south of the axis of the

syncline [29, p. 60, Fig. 6]. The stream appears to have been captured at the beginning of the 430-foot stage by stream A (Fig. 32), which thus initiated the lower part of the Stanmer Down-Brighton valley.

Against the possibility of such a capture it may be urged that the hypothesis outlined above demands that a short stream was able to cut through an anticline to capture a synclinal stream beyond. There are, however, three special points to be taken into consideration.

1. Although at the level of the Pliocene bench comparatively resistant *Micraster* Chalk was exposed in the core of the anticline and Tertiary sediments or soft Chalk in the syncline, stream A had probably reached the softer Middle Chalk by the 430-foot stage. The Geological Survey New Series 1-inch sheet No. 318 shows the base of the Upper Chalk at *c.* 250 feet O.D., but Osborne White's section [29, p. 60, Fig. 6] shows it at *c.* 430 feet O.D. at Hollingbury Castle. If the section is correct, erosion by stream A was facilitated at the 430-foot stage.

2. The southward down-dip migration of the synclinal stream, together with the northward advance of the coast under wave-attack during the 430-foot stillstand, effectively shortened the amount of headward erosion to be performed by stream A in the diversion of the synclinal stream. The northward movement of the coast must also have had the effect of steepening the gradient of stream A, thus increasing its power of erosion.

3. The well-developed 430-foot flat at Great Wood (328093) indicates that the Stanmer Down-Brighton stream possessed a marked elbow at this level. Such an abrupt bend is in accordance with the hypothesis of a capture at the beginning of the 430-foot stage.

(ii) *The Upper Lavant Valley*

The course of the Lavant, which rises in the pond at East Dean, is obviously of a compound nature. The upper portion, including the now dry eastward extension, follows approximately the crest of the Dean Valley anticline, but, at West Dean, it turns abruptly southwards to flow across the Chalk to the Coastal Plain (Fig. 33).

The Cocking gap has been regarded as marking the course of a north-south stream beheaded by the Sussex Rother, but, apart from Wooldridge and Linton's demonstration that the latter is a two-cycle subsequent stream entrenched in the mid-Tertiary peneplain [34], there are strong reasons for doubting that the Cocking stream was ever comparable with the major transverse rivers such as the Arun and the Adur.

If the distance between the 500-foot contours be accepted as an index of the importance of valleys in the area, the Cocking valley is seen to be slightly less important than the upper longitudinal Lavant,

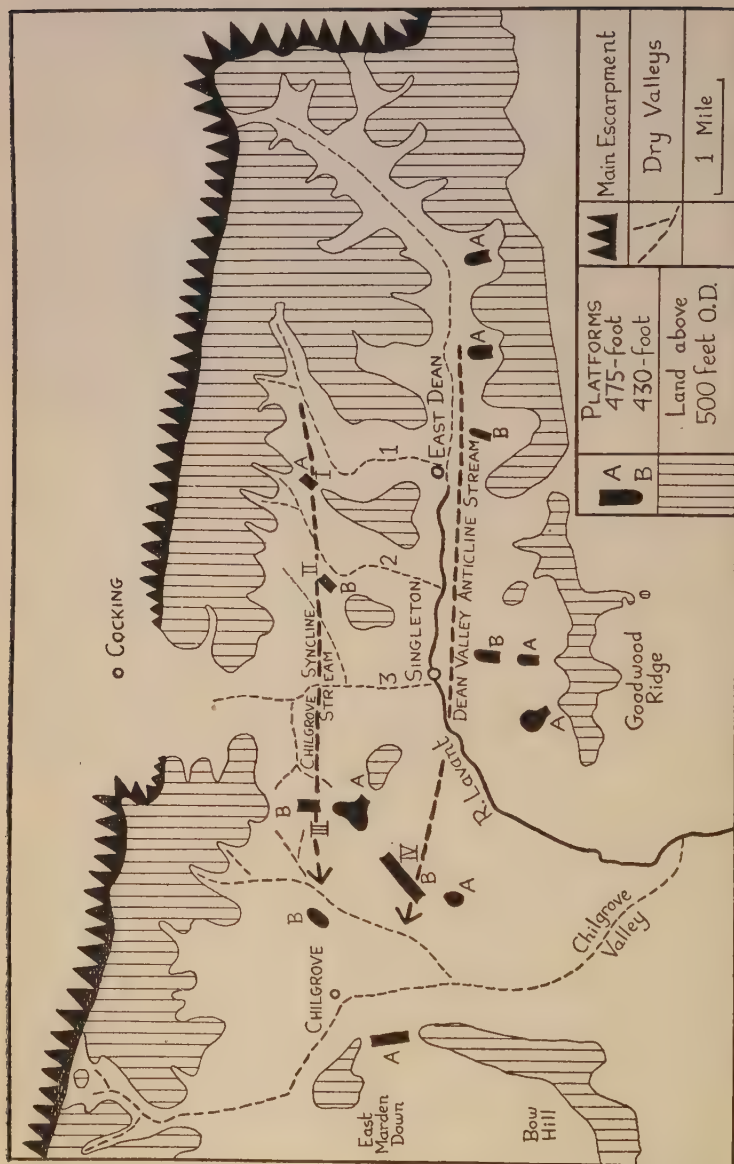


FIG. 33.—PRESENT VALLEY PATTERN AND RECONSTRUCTED 475-FOOT DRAINAGE OF THE UPPER LAVANT REGION.

and much less important than the Arun. Between Singleton and East Dean the Lavant valley is $\frac{3}{4}$ – $1\frac{1}{4}$ miles wide ; the Arun gap is $2\frac{1}{2}$ miles wide ; but the Cocking gap is little more than $\frac{1}{2}$ mile wide. Further, it can be demonstrated from the terrace fragments that the Arun gap was $1\frac{1}{2}$ miles wide at the 290-foot stage, and cannot have been narrower at the 330-foot stage, when the Cocking gap was an immature V-shaped valley. In addition, there is no evidence of the existence of a wide valley-floor in the Cocking gap at any earlier stage. Thus, the Cocking gap is in no way comparable with the main river gaps.

Wooldridge and Linton [34] have suggested that the composite valley from Cocking to Chichester was originally that of a super-imposed Pliocene consequent stream ; but it can be shown, from the occurrence on the south side of the valley of remnants of the 475-foot and 430-foot valley-floors, the former extending eastwards as far as the Chichester–Petworth road, that the upper longitudinal Lavant has been the dominant valley of the area since the early Pliocene.

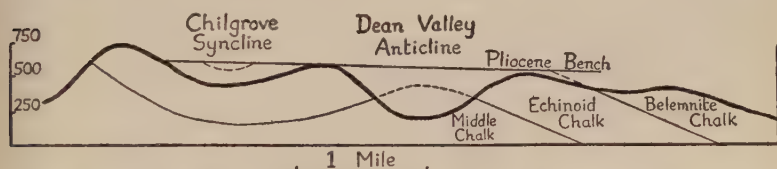


FIG. 34.—GENERALISED NORTH-SOUTH SECTION ACROSS THE UPPER LAVANT, showing relation between structure and relief, present outcrops of beds and reconstructed outcrops on Pliocene Bench. (Note outcrop of Belemnite Chalk (*Marsupites* zone) along axis of Chilgrove Syncline.)

Certain salient features of the relief of the area (Figs. 33 and 34) suggest a possible reconstruction of the drainage. North of the upper Lavant lies a discontinuous ridge exceeding 500 feet O.D., north of which is a narrow belt below 500 feet O.D., which coincides approximately with the Chilgrove syncline. The spurs crossing it preserve a number of cols at significant elevations along the axis of the syncline. Further, the dry valleys in the area north of the upper longitudinal Lavant are alined almost east–west along the syncline, but turn to the south, out of the syncline, with abrupt bends. Finally, the ridge to the west of the lower Lavant possesses two cols, the northern at approximately 430 feet O.D. roughly in line with the Chilgrove syncline, the southern, 700 yards in length and varying between 428 and 418 feet O.D. in elevation, approximately in line with the Dean Valley anticline.

The following hypothesis, stated uncritically for the moment, explains the facts stated above and recorded in Fig. 33. Although the area must have possessed a sub-parallel, north–south drainage

superimposed from the Pliocene cover at an early date, subsequent streams, one along the Chilgrove syncline and the other along the Dean Valley anticline, had integrated the drainage by the 475-foot stage. Not only the occurrence of the high terraces of the upper Lavant, but also the fact that the Goodwood ridge to the south is practically unbreached, add support to this view. The Chilgrove syncline stream and the Dean Valley anticline stream flowed westwards at the 475-foot stage across the ridge west of the lower Lavant to escape to the sea via the Chilgrove valley. A flat-floored, 475-foot col between Bow Hill and East Marden Down may mean that the streams united to escape into the upper Ems valley. The Ems valley is mapped as anticlinal by the Geological Survey, and it is tempting to regard the Ems and upper Lavant as the dismembered portions of a former subsequent stream occupying the crest of the Dean Valley anticline and its possible westward continuation. Gaster [14], however, has mapped the Ems valley as synclinal, and, until the structure of the area is finally known, the Chilgrove valley is preferred as the probable outlet for the streams. In any case, the possible westward outlet must have been abandoned after the 475-foot stage.

The anticlinal stream along the Dean Valley axis disrupted the Chilgrove syncline stream by means of its right bank obsequent tributaries. Obsequent 1 had, in fact, captured the head of the Chilgrove syncline stream at the 475-foot stage, leaving the 485-foot wind-gap at I (Fig. 33). Obsequent 3 and obsequent 2 completed the disruption at the 430-foot stage, leaving the 430-foot and 411-foot wind-gaps at III and II respectively. Thus, the first connection between the Cocking gap stream, a right bank resequent tributary of the Chilgrove syncline stream, and the Lavant was made at the 430-foot stage. At or about the same time, the present lower Lavant cut back to capture the Dean Valley anticline stream, leaving the pronouncedly flat wind-gap at IV. A later stage is represented by the 330-foot wind-gap at Cocking, which was abandoned as the incision of the Rother to the north caused the level of the water-table in the Chalk to fall. Probably two short feeders on the Gault outcrop would be sufficient to account for the width of the Cocking gap, and if that were so the stream was never beheaded by the Rother. Indeed, had the Rother not incised itself so rapidly in the non-resistant Sandgate Beds, it is probable that it would have been captured by the Cocking stream.

Although the argument outlined above explains fairly the present pattern and distribution of relief and platforms, some attention must be directed towards its implications. Thus, if the streams occupying the Chilgrove syncline and the Dean Valley anticline are to deserve the title subsequent, weak beds must have been exposed at or near the surface on which the streams were initiated, i.e., the early Pliocene marine bench. The disposition of strata shown on Gaster's map

[14] indicates that weak *Marsupites* Chalk was exposed along the Chilgrove syncline (Fig. 34), but, both from this map and from the Geological Survey map, it appears that the base of the Upper Chalk cannot have been much above 450 feet O.D. along the axis of the Dean Valley anticline. Thus, the weaker Middle Chalk cannot have been exposed at the surface on the Pliocene bench. Yet it is obvious that the anticlinal axis was occupied by a stream at the 475-foot stage, in spite of the apparent lack of sub-surface guidance. It is possible, though impossible to prove, that the upper Lavant merely reoccupied an old valley incompletely planed by the Pliocene sea.

Although the outcrops of the beds on the Pliocene bench explain only the Chilgrove syncline stream, the disposition of the beds affords ample reason for the later development of the valleys. From the level of the Pliocene bench to approximately 450 feet O.D., the Dean Valley stream was obliged to cut into the harder, lower beds of the Upper Chalk, while, for a brief period, the Chilgrove syncline stream excavated its valley in soft *Marsupites* Chalk. But, at 450 feet O.D., the Dean Valley stream, reaching the softer Middle Chalk, began a more rapid incision of its valley. At the same time the deepening of the valley occupied by the Chilgrove syncline stream was retarded by the presence of more-resistant *Micraster* Chalk. Thus, the advantage below 450 feet O.D. lay with the Dean Valley anticline stream, and the disruption of the Chilgrove syncline stream by its right bank obsequent tributaries was greatly facilitated, most of the captures taking place during the 430-foot stillstand.

The suggested capture by the lower Lavant of the westward-flowing, 430-foot, Dean Valley stream is more difficult to explain, but the explanation of the physical character of the ridge west of the lower Lavant is no easier, unless it be supposed that the two subsequent streams originally flowed across it. The geological objection is that the suggested capture requires the diversion of a subsequent stream, occupying the axis of an anticline, by a short consequent stream, and there appears to be little in the disposition of the beds to explain why diversion should have occurred. Although the Chilgrove valley, the original outlet, cuts across the ends of the folds, and may have had an early course across the softer, higher beds of the Upper Chalk, *Micraster* Chalk was certainly reached by the 430-foot stage. At the same time the upper Lavant was cutting, and presumably widening, its valley at least partly in the Middle Chalk. The head of the present lower Lavant, following the fall in base-level to 380 feet O.D., reached the softer Middle Chalk, while the Chilgrove valley, the former outlet of the Lavant, had still to cut through a considerable thickness of *Micraster* Chalk. Thus, the diversion of the upper Lavant occurred before the 380-foot rejuvenation had spread far up the Chilgrove valley, at least before it reached the broad 428-418-foot col (IV) west of the lower Lavant. Whether the suggestion is adequate to explain the capture is doubtful, and

it is perhaps preferable to conclude that the deductions from the present relief and those from the principles of stream development are in apparent conflict.

From this discussion of areas in which major longitudinal valleys interrupt the dip-slope, several conclusions, relevant to the discussion of other regions, may be drawn.

1. Where the recession of the shoreline from the Pliocene position to the 475-foot position exposed beds of differing lithology to sub-aerial erosion, subsequent streams were quickly formed.

2. There appear to have been two captures, possibly three, of the subsequent streams by headward-eroding, coastal, consequent streams, i.e., the North Moulsecomb-Brighton valley, the lower Lavant, and, possibly, the Chilgrove valley. Elsewhere, the barrier of high ground developed on *Micraster* Chalk has protected the subsequent streams from further capture. In all cases the presumed captures have taken place where the fold structures are dying out.

3. South of the barriers of high ground developed on *Micraster* Chalk, the drainage was initiated afresh as a series of sub-parallel, southward-flowing streams following the slope of the emerged 475-foot sea-floor. As the sea retreated the streams were extended across lower sea-floors, and new streams were probably added at later stages. Any possible development of subsequent streams has been prevented, as the area has been exposed to sub-aerial erosion for too short a period.

(c) The Secondary Escarpment

The areas of downland discussed under this heading are, as defined at the beginning of the section on valley development, the region west of the Lavant and the Arun-Adur block. The secondary escarpment is also found between the Lavant and the Arun, but it is well developed only in the extreme east of this area, the relief of which is dominated by the longitudinal upper Lavant.

In the field the secondary escarpment is a marked feature, a true escarpment, although dissected by numerous dry valleys into isolated hills, the scarp slopes of which face northwards. Due to differences of opinion as to the horizons of the lithological differences which cause the secondary escarpment, it is proposed, for the moment, to define the escarpment as developed in Chalk above the *M. coranguinum* zone. Thus, the southern sides of the upper Lavant and Lewes Winterbourne valleys, which, although scarp-like in form, are capped by *Micraster* Chalk, are excluded.

The published descriptions of the lithology of the Chalk of the South Downs by Clement Reid [25, 26], Brydone [2], Osborne White [29, 30] and Gaster [12] throw little light on the matter. Apart from the well-known difference in resistance between the Echinoid Chalk and the weaker, overlying Belemnite Chalk, there

are few lithological differences within the Belemnite Chalk, in which the secondary escarpment is developed. The whole of the Chalk above the *M. coranguinum* zone is described as soft, and, except in the *A. quadratus* zone, contains frequent marl-seams; indeed, Brydone [2] described 20 marl-seams in the 100 feet of Chalk assigned by him to the *O. pilula* zone.

It is not surprising, therefore, that opinion as to the exact horizon of the weakness has varied considerably. Brydone thought that, in Hampshire, the weakness occurred in the upper part of the *M. coranguinum* zone, thus giving rise to "an escarpment, sometimes quite a steep one, in which the *Uintacrinus* band occupies the lower part, and the *Marsupites* zone the upper part with often a capping of the zone of *O. pilula*." [1, p. 19.] Gaster [12] has quoted this statement with approval.

On the other hand Osborne White's views were different. They may be summed up by the following quotation: "The lowest 50 feet or so of the *Quadratus* Chalk, together with a variable thickness of the contiguous *O. pilula* beds, crop out in the secondary escarpment west of the Adur valley. . . . This feature is to be ascribed to the weakness of the *Marsupites* Chalk rather than to any exceptionally resistant property of the chalk above it" [29, p. 56]. With this opinion Wooldridge and Linton [34] agree, and, incidentally, so do Gaster's maps [12, 13, 14], which show the secondary escarpment west of the Adur to be capped everywhere either by *A. quadratus* Chalk or *O. pilula* Chalk. In spite of the scarcity of topographic detail on Gaster's maps, it appears that, where the capping is formed of *O. pilula* Chalk, there is at least a thickness of 120 feet of this zone. As Gaster [11] has transferred the *Hagenowia* beds, the lowest 60 feet of Brydone's *A. quadratus* zone, to the *O. pilula* zone, the escarpment is, therefore, everywhere capped, as Osborne White stated, by the *A. quadratus* zone (Brydone's definition). Further, Gaster's maps show the *Marsupites* zone to be stripped back in the manner described by Osborne White and Wooldridge and Linton. Only in the vicinity of the lower Cuckmere does Gaster [13] describe a secondary escarpment capped by *Marsupites* Chalk, a state to be expected if Brydone's diagnosis of the horizon of the weakness were correct. But in this area the escarpment consists only of east-west ridges, and is in no way comparable with the true development of the secondary escarpment west of the Adur.

It being established that the cap-rock is everywhere *A. quadratus* Chalk (Brydone's definition), the lithology of that stratum must be investigated more fully, as, in the formation of escarpments, the character of the cap-rock is of much greater importance than that of the beds found in the face of the escarpment. The point is clearly demonstrated by the main Chalk escarpment, where the relatively-weak Middle Chalk outcrops in the face of the escarpment, but is protected by a capping of the harder, lower beds of the Upper Chalk, the Echinoid Chalk.

Both from the published descriptions and from field observation the *A. quadratus* Chalk appears to be more massive than the *Offaster* and *Marsupites* Chalks below ; it certainly contains fewer marl-seams. Although the Chalk is not very hard, it would thus be more permeable than the marl-seamed zones below, less likely to nourish a surface drainage, and, consequently, less likely to be eroded. An analysis has been made of the percentages of insoluble residue throughout the zones in question, and, although none of the Chalk contains much residue, the highest proportion is found in the *Marsupites* and *Offaster* zones. In order to eliminate the possibility of abnormally high percentages of insoluble residue due to concentration by superficial solution, the samples for analysis were extracted from the centres of large blocks of Chalk. With the exception of the *Hagenowia* Chalk, which was obtained from a pit (168059) near Sompting, the specimens were taken from the pits on the southern side of Highdown Hill (093044), use being made of Gaster's zoning of the pits in the Worthing area [11]. The following analyses are averages based upon two determinations of the insoluble residue present in the sample selected.

Zone		Insoluble Residue (as per cent of dry weight of Chalk)	
<i>A. quadratus</i>	...	...	1.40
<i>Hagenowia</i> beds	...	...	1.90
<i>O. pilula</i>	...	...	4.10
<i>M. testudinarius</i>	...	...	3.33
<i>Uintacrinus</i> subzone	...	...	1.53

Assuming that these figures are representative for the Chalk of the South Downs, it would appear, both from the frequency of the marl-seams and from the percentages of insoluble residue, that the *Marsupites* and *Offaster* Chalks are less permeable than the Chalks above and below. Nevertheless, the lithological differences are not large, and it may be that stream-action has been a more delicate index of lithology than the geologist's hammer, for erosion has reacted in a striking manner to produce the secondary escarpment.

In the deduction of the drainage pattern which has etched out the secondary escarpment, the following facts are vital :—

1. The escarpment is dissected by north-south, sub-parallel valleys, which have the disposition of superimposed Pliocene consequent valleys. They are, however, probably too close together to have survived without integration since that date.

2. On the spurs leading north from the secondary escarpment hills there are marked flats, which were obviously formed during the 475-foot, 430-foot and 380-foot stillstands. Most of these are far too extensive to have been formed by general degradation of the ridges between the sub-parallel valleys. Such a process might

account for cols, but not for flats often exceeding 400 yards in length.

3. Where the secondary escarpment reaches its main development, it can be shown that the retreat of the sea from the Pliocene level to the 475-foot level exposed the weak *Marsupites* and *Offaster* beds to sub-aerial erosion. Where the escarpment is weakly developed, or non-existent, these beds were not exposed until much later.

These facts suggest that, by the time that the 475-foot stage was reached, the drainage was integrated by scarp-foot subsequent streams developed in the *Marsupites* and *Offaster* beds. The possibility of such rapid subsequent development has been fully demonstrated by the examples of the Lewes Winterbourne and upper Lavant valleys. The subsequents were probably short streams flowing into the main rivers, as is clearly suggested between the Arun and the Adur by the secondary escarpment forming an apex at Harrow Hill (Fig. 35). Later headward erosion by the short, coastal, consequent streams cut back through the secondary escarpment to disrupt the subsequents streams beyond. These captures occurred at different dates, but were complete by the 380-foot stage. Although this hypothesis explains the formation and dissection of the secondary escarpment, the pattern of the dry valleys and the distribution of the flats north of the secondary escarpment, it runs counter to the deduced relation between consequent and subsequent drainage. The former is normally regarded as a stable pattern, but the hypothesis outlined above demands that a subsequent drainage was able to maintain itself only for a short time before it was disrupted by a number of headward-eroding consequent streams.

Many of the difficulties in the way of the suggested captures disappear if the sea be regarded as a river flowing parallel with the scarp-foot subsequent stream. Given two parallel rivers, one in a tract of resistant rocks and the other in a tract of weak rocks, the possibility of the latter capturing the former, after a rejuvenation, would normally be accepted. In the present case the captures are even more plausible as one "river" was the sea and its reaction to a fall in base-level was instantaneous and complete. As the difference in elevation between base-level and the graded course of the scarp-foot subsequent stream was greatest near the head of the latter, the earliest captures should have taken place in that position: in general, this deduced condition is matched in the field.

The following additional points, each small in itself, help to explain the suggested captures:—

1. The initial integration of the drainage was facilitated by the fact that the subsequent streams were able to develop in the weak *Marsupites* and *Offaster* beds, while the lower parts of the Pliocene consequents had to cut through the more-resistant *A. quadratus* Chalk.

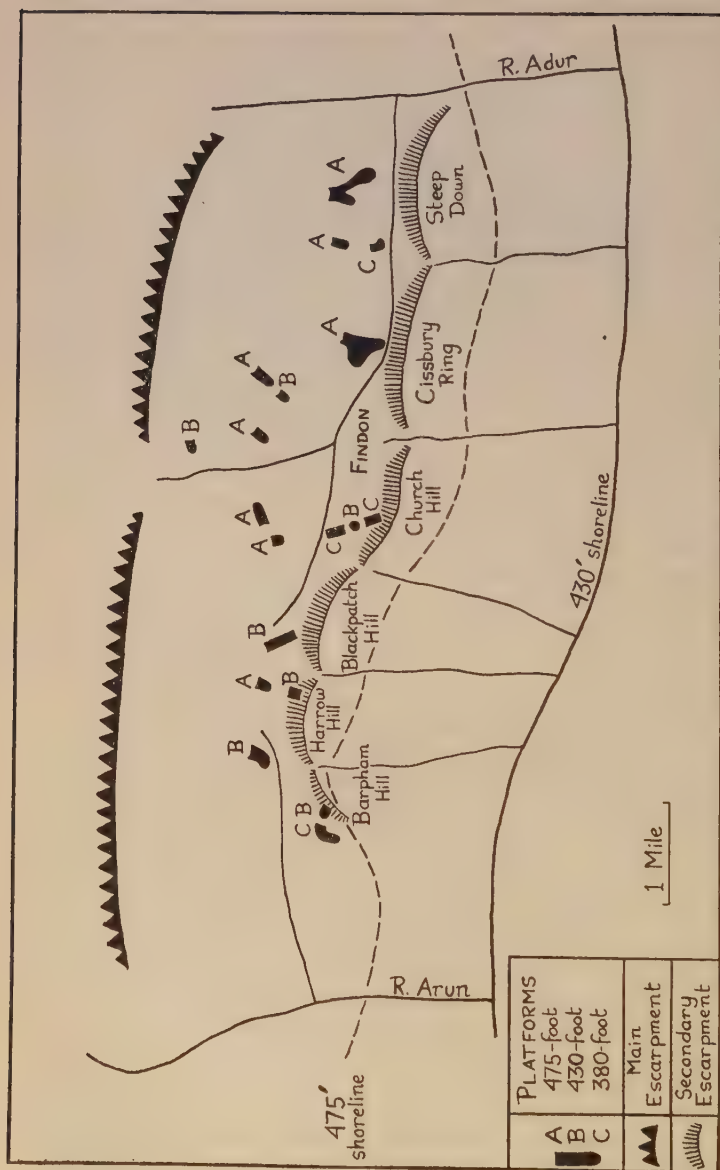


FIG. 35.—RECONSTRUCTED DRAINAGE OF ARUN-ADUR BLOCK AT BEGINNING OF 430-FOOT STAGE. (Note. The whole of the evidence of the 475-foot, 430-foot and 380-foot platforms north of the secondary escarpment is included, so that the escarpment is shown a little south of its 430-foot position).

2. As the slope of the Pliocene bench is less than the dip of the Chalk, uniclinal shifting by the subsequent streams resulted in the southern sides of their valleys forming escarpments of increasing height. In order to become adjusted to a fall in base-level, such a subsequent stream had either to migrate farther down-dip, a slow process due to the height of the escarpment, or to entrench itself into the resistant *Micraster* Chalk forming the floor of its valley. Thus, at this stage, the short, coastal stream, cutting down into *A. quadratus* Chalk, had an easier task than the scarp-foot subsequent : the initial position was, in fact, reversed.

3. During each stillstand, the northward movement of the shoreline under wave-attack effected a form of rejuvenation by shortening the streams and so steepening their gradients. As the absolute amount of shortening of the short, coastal stream was the same as that of the longer, scarp-foot subsequent, the relative steepening of the gradient of the former must have been greater. This must have partly offset the greater power, due to the greater volume, of the scarp-foot subsequent.

4. The northward movement of the shoreline during stillstands, coupled with the southward down-dip migration of the scarp-foot subsequent, effectively decreased the amount of headward erosion to be performed by the coastal stream in order to capture the scarp-foot subsequent.

5. While the foregoing suggestions help to explain the probability of the suggested captures, it is possible that a general desiccation of the Chalk was of greater importance. At each fall in the level of the water-table, the spring-head of the scarp-foot subsequent must have migrated laterally downstream for a considerable distance, but that of the coastal, consequent stream a much shorter distance, due to the stream's steeper gradient and proximity to the sea. Thus, the recession of the spring-heads of the coastal streams, at least during and after the 380-foot stage, may have done little more than disrupt a subsequent valley already dry or occupied by an intermittent stream comparable with the Lewes Winterbourne.

It may be tempting to turn to an alternative explanation of the dissection of the escarpment, namely a rise of the sea, which flooded slight wind-gaps through the escarpment. After the sea fell it is possible that the drainage would have been reorientated southwards through the secondary escarpment. Apart from the arguments already adduced against oscillations of sea-level at the 475-foot stage, such a rise fails to explain why the sea did not breach the *Micraster* Chalk to disrupt, in similar fashion, the upper Lavant and Lewes Winterbourne. On the other hand, the greater resistance of the *Micraster* Chalk would effectively retard erosion by the short, coastal streams. The presence of a breached secondary escarpment of Belemnite Chalk and two, virtually unbreached ridges of *Micraster* Chalk, is thus additional evidence that the breaches were due to sub-aerial erosion.

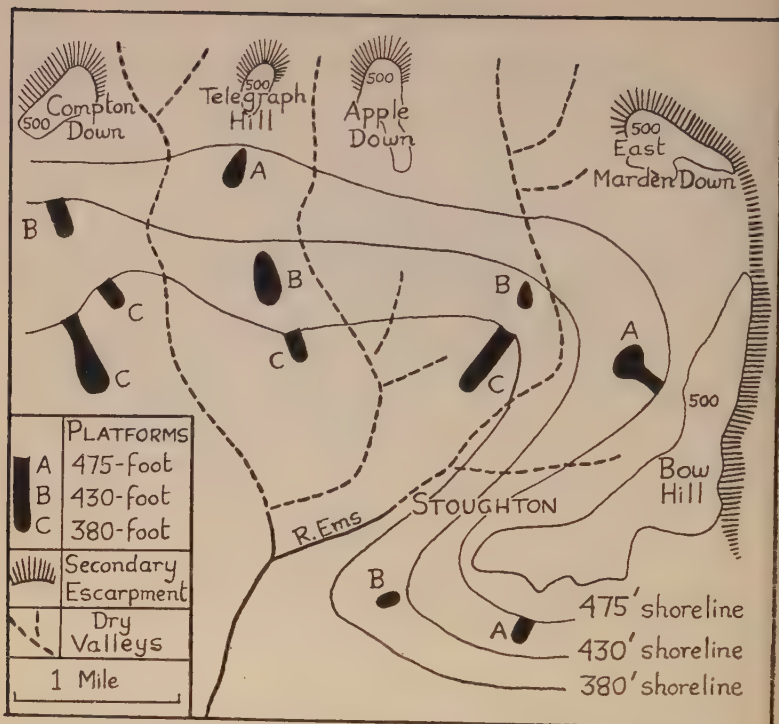


FIG. 36.—DRY VALLEY PATTERN NEAR STOUGHTON.

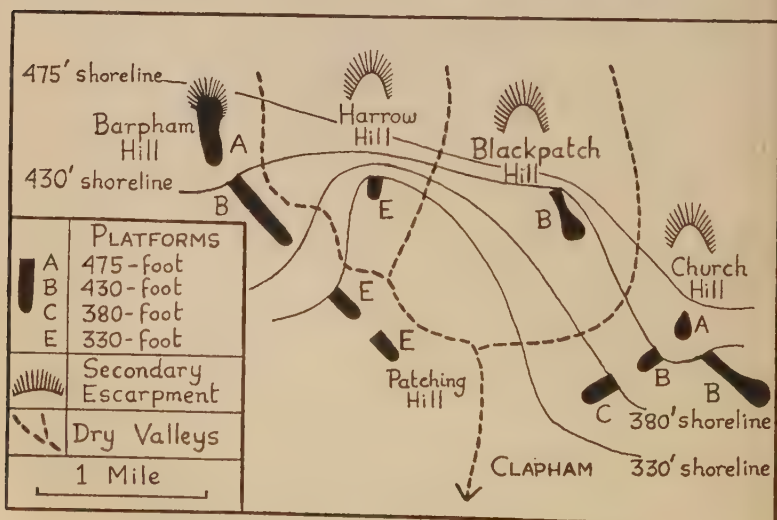


FIG. 37.—DRY VALLEY PATTERN NEAR CLAPHAM.

(d) Valley Development in Areas with a Simple Southern Slope

The Downs between the Adur and Brighton, and between the Ouse and Beachy Head, offer the best examples of simple dip-slope topography. As the weak *Marsupites* and *Offaster* beds were not exposed until after the 475-foot stage, there has been little development of subsequent valleys. Instead, the Pliocene consequent streams have been extended over a series of emerged sea-floors and have retained their sub-parallel character, while new consequents have been added from lower sea-floors. This is shown most clearly immediately west of Beachy Head. From Wooldridge and Linton's [34] reconstruction of the position of the Pliocene shoreline, it is apparent that the main Pliocene consequents must have flowed approximately north-south, as shown by the Ouse, Cuckmere and

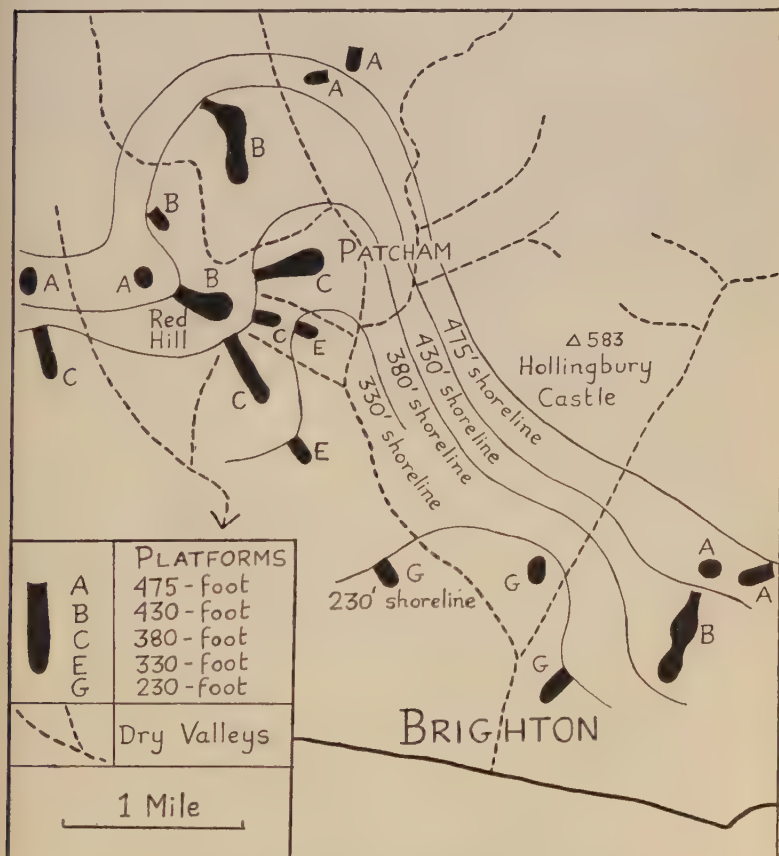


FIG. 38.—DRY VALLEY PATTERN NEAR BRIGHTON.

Jevington valleys. But all the lower shorelines turn abruptly southwards and disappear at Beachy Head. The general trend of dry valleys in this region is nearly east-west, thus conforming with the trend of the lower shorelines. It is obvious, then, that there are two generations of valleys here: Pliocene consequents, represented today by the main valleys, and a group of minor dry valleys, which were probably initiated during the 475-foot and 430-foot stillstands.

Although the general valley pattern of the areas under discussion is sub-parallel, there are a few localities where there has been some integration of the valleys. Figs. 36, 37 and 38 show three localities where there is a convergent pattern of dry valleys, namely at Stoughton, Clapham and Brighton. These are the only localities where Bull's description [4] of the dry valley pattern as dendritic is at all applicable. It is more than a coincidence that these three convergent valley patterns are found to occupy the sites of former marine embayments, usually at the higher of the stages under discussion. The Stoughton embayment was pronounced from the 475-foot stage until the 380-foot stage; the Clapham embayment was very shallow at the 475-foot stage, but increased steadily until the 330-foot stage, after which it disappeared; Patcham bay appears to have persisted right down until the 230-foot stage, when the streams, the valleys of which are followed by the main routes to London and Lewes, flowed into it separately. These embayments provide a simple explanation of the convergent valleys, as, following the retreat of the sea, the streams flowing into each bay united to follow the axial part of the emerged bay. Admittedly, two of the embayments are in areas where there is a secondary escarpment, but they lie to the south of it where valley development was similar to that in areas of simple southern slope.

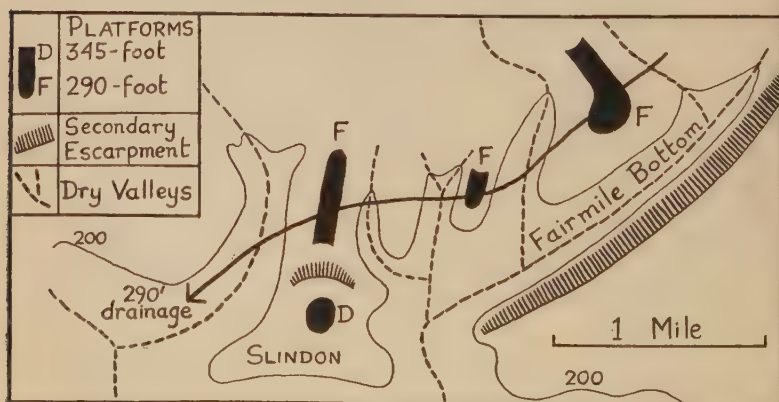


FIG. 39.—FAIRMILE BOTTOM.

Fairmile Bottom (Fig. 39), which is followed by the main London-Bognor road, is interesting, as it demonstrates the formation of a subsequent valley in the weak *Marsupites* and *Offaster* beds, the southern side being an escarpment formed of *A. quadratus* Chalk. From the position of the shorelines in the region, it is apparent that the valley cannot have been initiated until after the 430-foot stage. Later uniclinal shifting is evident from the position of the 290-foot flats on the northern side of the valley. The remarkable 290-foot flat to the north of Slindon clearly suggests that the Fairmile Bottom stream escaped to the west at this stage. Its present outlet was presumably initiated by processes similar to those which have dissected the secondary escarpment elsewhere. In fact, Fairmile Bottom represents the secondary escarpment in embryo, development having been arrested by the desiccation of the Chalk.

5. DRY VALLEYS

It has been implicit throughout this discussion that the dry valleys of the South Downs were formed quite early in the evolution of the area by the action of running water. As such a view is not universally held, the origin of dry valleys must be briefly discussed.

Broadly speaking, there are two reasonable schools of thought concerning the origin of dry Chalk valleys. That initiated by Clement Reid [24], and followed by Osborne White [29], held them to be troughs scoured out by melt-water in the Pleistocene, when the chalk was rendered impermeable by being frozen. The only difference of opinion between Clement Reid and Osborne White concerned the nature of the climate, the former postulating a cold, arid climate and the latter a cold, wet climate.

On the other hand, Chandler [7] and Fagg [9] regarded the dry valleys as old stream valleys abandoned owing to a fall in the level of the water-table within the Chalk. The mechanism controlling the level of the water-table is the elevation of the Gault Clay outcrop, which is, in turn, mainly controlled by the position of the Chalk escarpment. Chandler further emphasised the rounded heads of the valleys, which he thought were due to the recession of springs. It is interesting to note that the melt-water hypothesis has been derived from studies made on the South Downs, while Chandler and Fagg based their views on studies of the North Downs.

Bull, who has studied certain features of the geomorphology of the South Downs in great detail, has maintained a position midway between the two extremes. In 1936 [4] he considered that melt-water had scoured out a pre-existing drainage pattern, but in 1940 [5] he brought forward specific arguments against Fagg's hypothesis, a consideration of which is deferred for the moment.

The intermittently-falling base-level, demonstrated by the sequence of platforms found in the South Downs, provides a

mechanism which controlled the level of the water-table within the Chalk. The basic control has been sea-level, which sets a minimum elevation to which the Gault can be lowered. A large, rapid fall in the level of the water-table within the Chalk cannot have occurred at any stage. There is no reason to assume that the streams flowing across the Chalk were unable to adjust themselves to the 50-foot falls in base-level, as the water-table within the Chalk could not have fallen a corresponding amount until either the Gault was lowered or the Chalk drainage was entrenched.

However, headward erosion by the springs near the escarpment must have been offset by the southward migration of the springs, which occurred at each successive lowering of the level of the Gault outcrop. It appears, from the desiccation of the Cocking, Findon, Pyecombe and Jevington gaps, that the fall of base-level, which was accelerated late in the period under discussion, finally dried the valleys from the head downwards.

One last point emerges : the dating of the valleys is no longer a clear issue between Pliocene and Glacial, because they may have been formed on any one of the emerged sea-floors, this being most clearly shown at Beachy Head, as outlined above. Indeed, the majority of the dry valleys were probably initiated from the lower sea-floors, the major dry gaps being the only certain Pliocene valleys.

The first of Bull's objections [5] to Fagg's hypothesis is that the dry valleys rarely breach the crest of the Downs. This he takes as evidence that some of them have been cut by melt-water flowing from snowfields capping the Downs. But the certain Pliocene valleys amply breach the escarpment, and there is a simple explanation why other breaches do not occur. The majority of the dry valleys, initiated from the 475-foot and lower sea-floors, have been able to effect but little headward erosion near the crest of the Downs. As the recession of the main escarpment has nowhere reached the 475-foot shoreline, most of the valleys cannot be expected to notch the crest of the Downs. This is especially easy to demonstrate in the area immediately north of Beachy Head on which Bull based his study.

Secondly, Bull [5] objected that the valleys have not the abrupt, rounded heads characteristic of spring heads. Bull himself [4] had previously remarked on the number of valleys that do exhibit rounded heads, and the earlier statement appears to be much nearer the truth.

Thirdly, Bull [5] has suggested, from the presence of the 320-foot terrace on the scarp-face, that the main escarpment can have retreated little since that time. But these flats merely prove that the upper part of the escarpment has not retreated. Assuming an elevation of 90 feet O.D. to sea-level for the Gault in the Eastbourne

area and a regional dip of $2\frac{1}{2}$ degrees, as used by Bull in his reconstruction of the area [5, Fig. 11], and assuming also that, at the 320-foot stage, the Chalk-Gault junction was at an elevation of 320 feet O.D., it follows that :—

1. Where the 320-foot terrace has been destroyed, the lower part of the Chalk escarpment has retreated at least $1-1\frac{1}{2}$ miles since the 320-foot stage.

2. Where the 320-foot terrace has not been destroyed, the lower part of the escarpment has retreated $1-1\frac{1}{2}$ miles less the width of 320-foot terrace preserved. Nowhere does this terrace exceed one quarter of a mile in width, and it is normally much less.

3. At the 320-foot stage the level of the water-table within the Chalk cannot have been below 320 feet O.D. That there was abundant surface drainage is proved by the fact that the terrace was originally cut into the Chalk for a distance of $1-1\frac{1}{2}$ miles.

4. There is, therefore, ample reason for presuming that a surface drainage, inherited from earlier times, existed on the Chalk dip-slope.

In short, the recession of the upper part of the escarpment is of little moment as it does not control the elevation of the Gault outcrop. The recession of the lower part of the Chalk escarpment, controlling the elevation of the Gault, and, thus, the level of the water-table within the Chalk, has caused the Gault to be lowered from 320 feet O.D. to between 90 feet O.D. and sea-level since 320-foot times.

Thus, none of Bull's objections really invalidate the application of Fagg's hypothesis to the origin of the South Downs dry valleys. There are, however, serious objections to the melt-water hypothesis if it be presumed that no pre-glacial, dry valley pattern existed and an attempt be made to explain the dissected secondary escarpment. In order to explain the condition of this escarpment, one of two highly improbable hypotheses must be assumed :—

1. That melt-water, flowing from the crest of the Downs, etched out the weak *Marsupites* and *Offaster* beds. Then, having lowered this strike vale to a series of steps corresponding exactly with the elevations of former platforms, the melt-water was prevented from escaping via the main river gaps by 600-foot thick valley glaciers, and so trenced a series of closely-spaced outlets through the secondary escarpment. Needless to say, there is not the slightest evidence that such monstrous glaciers ever existed in the South Downs.

2. That melt-water flowed directly south, and, by some means, widened its channels so that the ridges between them were lowered, along the outcrop of the weak beds, to remarkable flats according precisely with the elevations of former platforms. Meandering streams might conceivably effect this lowering, but certainly not melt-water. Furthermore, this hypothesis does not explain why

the secondary escarpment is found well developed only where the 475-foot shoreline lay south of the outcrop of the *Marsupites-Offaster* beds on the Pliocene bench.

The valley-pattern in areas where there is a dissected secondary escarpment must, therefore, be pre-glacial; the same is probably true of other areas. The writer is not concerned to deny that melt-water has modified the form of the valleys: numerous sharply-undercut, concave bends suggest that modification has, indeed, occurred. The melt-water hypothesis, however, seems not only unnecessary but also inadequate to explain the origin of any dry valleys, except perhaps such minor trenches as the Devil's Dyke (260110) [27 in discussion] and the Coombe at Lewes (428108).

CONCLUSION

Due to their arrested dissection and proximity to the sea, the South Downs have preserved a full record of the changes in base-level between the early Pliocene and Boyn Hill times in the form of erosional platforms. Other areas of southern England show platforms at similar elevations, but no region appears to possess as complete a record as the South Downs.

Although certain conclusions as to the development of a few valleys have been stated, the acceptance of the other hypotheses depends upon acceptance of the assumption that headward erosion of consequent streams has diverted a subsequent drainage under special conditions. If the possibility of this be accepted, then the present form of the South Downs, the distribution of platform fragments, and the dissection of the secondary escarpment are all explicable: if the deduced reaction of drainage is held to render such diversions impossible, there is no satisfactory explanation of the typical features cited above. Further, it has been shown that there is no fundamental objection to the application of Fagg's hypothesis to the origin of the dry valleys of the South Downs.

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APPENDIX : SUMMARY OF PLATFORM FRAGMENTS

The following tables give details of the location, height-range, length, origin and horizon of all the flats, isolated hills and cols surveyed in the field. In order to tabulate, the following abbreviations have been used :—

1. The origin of each flat is indicated after the name of the locality, (M) signifying a marine origin and (S) a sub-aerial origin.

2. The zone or zones on which each flat is developed is indicated by the initial letters of the generic and specific names of the zone fossil. The zoning used is that published by Gaster [12, 13, 14]. The abbreviations used are as follows :—

A.q.	<i>Actinocamax quadratus</i> .
O.p.	<i>Offaster pilula</i> .
M.t.	<i>Marsupites testudinarius</i> .
M.c-a.	<i>Micraaster coranguinum</i> .
M.c-t.	<i>Micraaster cortestudinarium</i> .
H.p.	<i>Holaster planus</i> .
T.l.	<i>Terebratulina lata</i> .
I.l.	<i>Inoceramus labiatus</i> (<i>Rhynchonella cuvieri</i>)

Locality and Origin	Grid Reference	Elevation (Feet O.D.)	Length (Yards)	Stratum
The 475-foot platform.				
1. Blendworth Down (M)	713148	455-450	150	
2. Chalton Down (M)	734150	476	Summit	
3. Ladyholt Park (S)	758166	473	700	M.t./M.c-a.
A broad, flat-topped area by the 473-foot Trigonometrical Station is isolated from higher ground by a slight sag, and thus only the elevation of the front of the flat is given. The length given assumes that the back of the flat was at approximately 480 feet O.D.				
4. Telegraph Hill (M)	782144	488	Summit	A.q.
This isolated, flat-topped swell may represent a degraded flat, but the elevation is high for the marine 475-foot platform.				
5. Apple Down (S)	797157	458-454	250	M.t./M.c-a.
This lies on the spur leading north from the secondary escarpment hill, Apple Down.				
6. Funtington Down (M)	809100	453-450	110	A.q.
Exact observation is difficult owing to the presence of dwarf, spreading yews.				
7. North Marden (S)	812161	489-487	350	M.c-a.
8. Lambdown Hill (M)	819126	467	600	A.q.
The elevation quoted is that of the forward edge. The length is based upon the assumption that the flat extended south-eastwards to the 482-foot spot height on Stoughton Down.				

	Locality and Origin	Grid	Elevation	Length	Stratum
		Reference	(Feet O.D.)	(Yards)	
9.	(S)	829139	475-465	350	A.q.
This flat-floored col connects East Marden Down and Bow Hill. It may have been formed by headward erosion of one of the dry valleys tributary to the Ems, but probably represents an early outlet of the Dean Valley anticlinal stream.					
10.	Heathbarn Down (S)	848128	487	Summit	M.c-a.
11.	Colworth Farm (S)	861141	463-455	450	M.c-a.
This small plateau is quite distinct from Hat Hill (513 feet O.D.) to the east.					
12.	(S)	873116	491-489	450	M.c-a.
This and flats 13, 15 and 16 are remnants of the 475-foot valley-floor of the upper Lavant.					
13.	Knights Hill (S)	880117	473-457	230	M.c-a.
Although sloping, this represents a flattening in the general slope of the spur.					
14.	(S)	904148	485	Col	M.c-a.
15.	Astead Down (S)	922122	489-475	350	M.c-t.
16.	Benges Wood (S)	936123	489-478	300	M.c-t.
17.	Nore Hill (M)	950101	474	Summit	A.q.
18.	Rewell Hill (M)	999100	478	Summit	A.q.
19.	(S ?)	002115	450	Summit	M.c-a.
This feature, north of the secondary escarpment, may not be significant.					
20.	Whiteways Plantation (S?)	003103	489	Summit	O.p.
This summit may not be significant.					
21.	Lonebeech Plantation (M)	009100	460	Summit	O.p.
No 450-foot contour encloses this summit on the O.S. 6th Edition map.					
22.	Barpham Hill (M)	067098	469-459	400	O.p./A.q.
Erosion has destroyed the back and dissected the flat into two knolls.					
23.	Harrow Hill (S)	084110	477		M.c-a.
The elevation quoted refers to the forward edge : the back cannot be fixed as the spur flattens gradually.					
24.	Highden Barn (S)	108107	479-477		M.c-a.
The back of this small flat is missing.					
25.	Highden Barn (S)	110108	456-455	500	M.c-a.
The back has probably been slightly lowered.					
26.	Church Hill (M)	112078	457		A.q.
The back of the flat has been destroyed : the elevation refers to the forward edge, reduced, at present, to an isolated hill.					
27.	(S)	125109	462-460	200	M.c-a.
28.	Middle Brow (S)	134108	498-485	450	M.c-a/M.c-t.
29.	Mount Carvey (M)	138076	464-446	400	A.q.
Both the forward and rearward portions have suffered from erosion.					
30.	Fox Down (S)	138093	482-465	700	M.c-a.
This is a small triangular plateau, 700 yards north-south and 500 yards east-west.					
31.	Lychpole Hill (M)	151074	449-448	150	O.p.
32.	Park Brow (S)	155095	475-452	250	M.c-a.
This flat is not very obvious, as it represents only a slight flattening in the slope of the spur.					
33.	Hill Barn (S)	162095	483-468	350	M.c-a.
34.	Hill Barn (S)	162095	483-450	900	M.c-a.
The last two flats have a common back, but are separated by a gully to the south. The eastern one (No. 34) has a sag to 440 feet O.D. in the middle.					
35.	Thundersbarrow Hill (S ?)	225095	480-491	1400	O.p./M.t./M.c-a.
This flat is a little too high to have been submerged by the 475-foot sea, and parts of it, at least, must have formed low islands.					
36.	Cockroost Hill (M)	247098	473-448	1100	
Erosion has isolated and lowered the forward edge.					
37.	Dyke Hovel (M)	256099	475-458	350	

	Locality and Origin	Grid Reference	Elevation (Feet O.D.)	Length (Yards)	Stratum
38.	Round Hill (M)	268085	445	Summit	
39.	(S)	271095	473	Col	
	This col, which is almost flat for a distance of 300 yards, appears to be too extensive to be attributed to headward erosion of the valley to the south.				
40.	(M)	279086	448	Summit	
41.	Scare Hill (M ?)	298105	451-448	100	
42.	Scare Hill (S ?)	300106	477-470	150	
	These last two flats are present on the same spur : they may represent the marine and sub-aerial stages of the 475-foot platform, or two minor marine stages of the 475-foot platform.				
43.	Tegdown Hill (S)	316104	489-474	350	
	The back has been destroyed by erosion.				
44.	(S)	323093	480	300	
	The elevation quoted refers to the forward edge as the back has been lowered to 470 feet O.D. Thus the length given is an approximation.				
45.	Race Hill (M)	342057	471-462	800	
	The flat is lowered to 442 feet O.D. in the middle.				
46.	Balmer (S)	359102	478-469	250	
	This and the next three flats are on the northern side of the Lewes Winterbourne valley.				
47.	(S)	365103	482	150	
	The elevation refers to the forward edge as the back has been lowered to 474 feet O.D.				
48.	Lewes Racecourse (S)	384117	450-452	500	
	The back has been slightly lowered.				
49.	Lewes Racecourse (S)	393114	446	Summit	
	This flat has been largely destroyed by the deepening of the valley to the north.				
50.	Malling Hill (S)	432111	463-459	200	
	There is a sag to 456 feet O.D. in the middle of the flat.				
51.	Mount Caburn (S)	444089	491	Summit	
52.	(S)	447097	489	Summit	
53.	Itford Hill (S)	443055	453		
	The back cannot be fixed as the slope flattens gradually.				
54.	Blackcap Hill (M)	467051	452-443	470	
	Erosion has certainly lowered this flat.				
55.	Overhill Lodge (M)	475054	476-472	300	
56.	Norton Top (M)	486033	467	Summit	
57.	(M)	499030	449	Summit	
58.	Long Brow (M)	551007	450-446	300	M.c-a.
59.	(M)	553007	472-467	200	M.c-a.
60.	Pea Down (M)	573990	450		M.c-a.
	This is only a slight flattening.				
61.	Bullock Down (M)	589964	458-450	350	M.c-a.

The 430-foot platform.

1.	Clanfield Down (S)	716170	428	Col	
2.	Chalton Down (M)	734146	423-421	350	
3.	Horsley Farm (M)	764138	420-418	300	A.q.
	This flat is at least 100 yards broad.				
4.	Old Locksash (M)	785133	403		A.q.
	The back has been eroded, but the 400-foot contour encloses an area 650 yards by 350 yards, no part of which exceeds 403 feet O.D.				
5.	Telegraph Hill (S)	788156	411-409	350	M.t./M.c-a.
6.	Walderton Down (M)	797101	410	Summit	A.q.
7.	(M)	808131	404	Summit	A.q.
8.	Hill Land Corner (S)	815150	426	Col	M.t.

Locality and Origin	Grid Reference	Elevation (Feet O.D.)	Length (Yards)	Stratum
9. Stoke Clump (M)	832096	406	Summit	A.q.
10. Stapleash Down (S)	842146	416	Summit	M.t.
11. Warren Down (S)	852139	428-418	730	M.c-a.
This flat, which tilts to the south, probably represents a former course of the Lavant.				
12. Colworth Farm (S)	860149	c. 430	Col	M.c-a.
13. Knights Hill (S)	880122	421-419	260	M.c-t.
This and No. 15 are remnants of a former valley-floor of the Lavant.				
14. Yorkhurst Hill (S)	890146	411	Col	M.c-a.
15. Bullsdown Clump (M)	900102	420		O.p.
The back of the flat has been eroded : the original length appears to have been approximately 600 yards.				
16. (S)	911123	413-409	220	M.c-t.
This may be a false flat caused by a gully on the western flank of the spur.				
17. Halnaker Hill (M)	921097	420	Summit	A.q.
18. Nore Hill (M)	953100	426-416	430	A.q.
19. Great Down (M)	969112	408		M.t.
The height quoted refers to the forward edge of the flat, the back of which is a gradual flattening.				
20. Home Farm (M)	975109	430-431	300	O.p.
21. The Denture (M)	987117	406-396	250	M.c-a.
22. Dry Lodge Plantation (M)	014097	425	Summit	A.q.
23. Barpham Hill (S ?)	065099	430-430	100	O.p.
24. Barpham Hill (M)	068091	425-404	700	A.q.
25. (S)	073113	411		M.c-a.
The back is impossible to fix as the flat merges into higher ground with no abrupt break of slope. The elevation quoted refers to the forward edge.				
26. Harrow Hill (S)	082105	401	Col	M.t.
27. Blackpatch Hill (S)	090110		Col	M.t./M.c-a.
The lowest point on this spur is 403 feet O.D., but for 1100 yards the spur ranges between 403 and 428 feet O.D., with the exception of a small area which reaches 441 feet O.D.				
28. Blackpatch Hill (M)	099091	403	300	O.p.
The elevation refers to the forward edge : the back has been lowered to 398 feet O.D.				
29. Muntham Court (S)	110095	408	Summit	M.t.
30. Church Hill (M)	110077	411-400	80	A.q.
31. High Salvington (M)	114076	421-420	700	A.q.
The valley to the north has caused a lowering to 418 feet O.D. in the middle of the flat.				
32. Washington (S)	124120	431-427	150	I.l.
33. Middle Brow (S)	130106	430-420	150	M.c-a.
34. Lychpole Hill (M)	154070	428		A.q.
This is only a very slight flattening.				
35. Annington Hill (S)	168089	423-412	350	M.c-a.
A shallow gully on its southern flank does not appear to have been the cause of the flat.				
36. Steep Down (M)	170073	422-402	200	O.p.
37. Thundersbarrow Hill (M)	231079	401-394	200	
38. Tenant Hill (M)	240095	430-405	230	
The rear limit is difficult to fix as the spur flattens gradually.				
39. Mount Zion (M)	249091	418-408	850	
The back has been eroded slightly and is at 410 feet O.D.				
40. Skeleton Hovel (S)	268091	422-420	150	
41. (M)	280091	420-410	200	
42. Red Hill (M)	281084	429-430	450	
The forward part is slightly higher than the rear.				

	Locality and Origin	Grid Reference	Elevation (Feet O.D.)	Length (Yards)	Stratum
43.	Sweet Hill (M) The back has been lowered to 418 feet O.D.	284102	429-420	900	
44.	Hollingbury Castle (S)	323087	430	Col	
45.	Great Wood (S)	328093	428-410	700	
46.	The Ridge (S) This and the next five flats lie in the Lewes Winterbourne valley.	350102	430-425	300	
47.	(S) This is a slight flattening in the slope of the spur.	351079	422-406	100	
48.	(S) This is not a well-defined flat, but a break of slope at the elevation indicated.	354080	418		
49.	Bunkershill Plantation (S) The spur flattens slightly at the elevation quoted.	366101	424		
50.	Balmer Down (S)	369111	430-420	300	
51.	Lewes Racecourse (S) Erosion has caused a sag to 399 feet O.D. in the middle of the flat.	384109	428-411	600	
52.	Offham Hill (S)	395116	418-414	300	
53.	(S) This may not be significant.	440106	426-425	100	
54.	Mount Caburn (S) A slight sag occurs in the middle of this flat.	443091	420-415	200	
55.	Ranscombe Camp (S) This is too high to be considered as the forward portion of the preceding flat.	438093	432	Summit	
56.	Race Hill (M) Erosion has destroyed the back and lowered the front of this flat.	332054	413-398	1000	
57.	Brighton Racecourse (M) The back has been lowered to 417 feet O.D.	345051	426-414	400	
58.	Wick Barn (M) The back has been lowered to 423 feet O.D.	354057	429-426	300	
59.	(M)	366056	415-400	300	
60.	The Bostle (M)	370051	428-415	350	
61.	The Bostle (M) A sag to below 400 feet O.D. occurs in the middle of the flat : thus the length is approximate.	374050	423-411	800	
62.	Pickers Hill—Highdole Hill ridge (M) Erosion has caused two lowerings to below 400 feet O.D., but the flat is still easily recognisable.	391051	428-414	1950	
63.	Fore Hill (M) The back is missing.	458044	424-418	170	
64.	Heighton Hill (M) The back has been destroyed.	477042	412-410	580	
65.	(M)	497029	428-418	90	
66.	(M)	500027	430	Summit	M.c-a.
67.	Fore Down (M)	537018	433	Summit	M.c-a.
68.	Fore Down (M) These last two summits, 450 yards apart, were probably parts of one flat.	534015	402	Summit	M.c-a.
69.	(M) This is merely a slight flattening.	552001	426		M.c-a.
70.	Friston Dencher (M) The forward part of this flat has been slightly lowered.	559993	415-402	670	M.t./M.c-a.
71.	Long Down (M)	588970	434-419	500	M.c-a.
The 380-foot platform.					
1.	Chalton Park (S)	734161	388-386	430	
2.	Compton Down (S)	766159	380-376	350	M.t./M.c-a.
3.	Lodge Farm (M)	767127	375-373	700	A.q.
A slight sag occurs at the back of the flat.					

Locality and Origin	Grid Reference	Elevation (Feet O.D.)	Length (Yards)	Stratum
4. Nore Down (M)	769130	384-382	200	A.q.
This may be a false flat produced by the action of a gully on the western flank of the spur.				
5. Lyecommon (M)	788127	382-379	240	A.q.
6. Inholmes Wood (M)	806128	377-375	660	A.q.
7. Camp Hill (S)	048114	383-375	250	M.c-a.
8. Perry Hill (M)	055092	380-370	200	O.p./A.q.
The back is difficult to fix as the flat merges into higher ground.				
9. Perry Hill (S)	061101	370-370	400	O.p.
This extremely flat area is separated from Perry Hill (390 feet O.D.) by a sag to 349 feet O.D.				
10. Clapham Wood (M)	106074	375-369	200	A.q.
Thick coppice makes exact observation difficult.				
11. Muntham Court (S)	108099	380-374	200	M.c-a.
12. Muntham Court (S)	110093	376-370	300	M.t.
These last two flats are separated by a low knoll (110095), a remnant of the 430-foot platform.				
13. Park Brow (S)	154089	376-375	150	M.c-a.
14. Annington Hill (S)	172090	377-374	150	M.c-a.
15. Round Hill (M)	269081	382-374	650	
The back is difficult to fix as the spur flattens gradually.				
16. Tongdean (M)	287080	374-358	700	
17. Red Hill (M)	290081	382-377	100	
18. Coney Hill (M)	290086	380	600	
Erosion has lowered the back of this small plateau to 366 feet O.D. at the windmill.				
19. The Ridge (S)	350096	377-374	280	
This and the next five flats are in the Lewes Winterbourne valley.				
20. Westlain Plantation (S)	350082	367-365	100	
This is somewhat low as it must be sub-aerial in origin : it may belong to the 345-foot platform.				
21. (S)	360084	392-388	200	
22. Bunkershill Plantation (S)	369100	387-385	250	
23. Balmer Down (S)	373109	389-387	200	
24. Lewes Racecourse (S)	396109	376-366	480	
25. Brighton Racecourse (M)	345045	378-363	500	
This appears to consist of two flats separated by a slight break of slope, but, as the construction of the golf course may have affected the slope, the evidence is insufficient to suggest that the platform is composite.				
26. Mount Pleasant (M)	356046	368	Summit	
27. High Hill (M)	378042	382	300	
The back has been lowered to 375 feet O.D. ; the elevation quoted refers to the forward edge.				
28. Highdole Hill (S ?)	400046	381-372	150	
The rear half of this flat is almost horizontal ; the front portion is more sloping, but quite distinct from the bluff, which separates the whole flat from the 345-foot flat to the east.				
29. The Comp (M)	488028	385-370	700	
This flat is slightly dissected.				
30. (?)	507033	362-358	200	M.c-t.
The position of the flat suggests a sub-aerial origin, but the elevation is very low for the sub-aerial 380-foot stage.				
31. The Rails (M)	507023	385	Summit	M.c-a.
32. South Hill, Friston (M)	549980	370-363	730	M.t.
33. Friston (M)	552978	364-362	350	M.t.
These last two flats appear to be distinct from the 380-foot area immediately south of Friston church.				
34. Bullock Down (M)	579964	380-374	200	M.c-a.

Locality and Origin	Grid Reference	Elevation (Feet O.D.)	Length (Yards)	Stratum
The 345-foot platform.				
1. Long Down (M)	936100	343	Summit	O.p.
2. Slindon (M)	966089	345	Summit	A.q.
3. Arundel Park (M)	020091	344-342	120	A.q.
This has possibly, but not probably, been caused by headward erosion of the valley to the west.				
4. Tenants Hill (M)	149068	345-332	300	A.q.
5. Annington Hill (S)	175092	346-340	100	M.c-t.
6. Lancing Ring (M ?)	179068	342-344	100	O.p.
The lower elevation at the rear appears to be due to a gully on the southern flank of the spur.				
7. (M)	211080	343	Summit	A.q.
8. Southwick Hill (M)	237078	343		
This is a slight flattening which may not be significant.				
9. Foredown Hill (M)	252079	342	Summit	
The 375-foot contour enclosing this summit on the 1 : 25,000 O.S. Provisional edition map is inaccurate.				
10. Lewes Racecourse (S)	387102	346-345	80	
11. Tenant Hill (M)	393031	346-338	350	
12. Fore Hill (S ?)	404045	345-338	400	
The 330-foot platform.				
1. Warren Down (M)	754122	320		A.q.
2. Firtree Piece (M)	759119	c. 330-315		A.q.
Both these flats are doubtful, as recognition is difficult due to the gentle regional slope and the thick tangle of undergrowth at Firtree Piece. The Warren Down flat appears to be a slight flattening at the level indicated.				
3. Hylters (S)	839139	325-322	400	M.t.
4. Cocking gap (S)	874160	c. 330	Col	H.p.
5. Lavant Down (M)	878100	319		O.p.
The height refers to the forward edge as the back has been eroded : the original length appears to have been approximately 300 yards.				
6. Halnaker Park (M)	910098	303-299	350	O.p.
7. Halnaker Park (M)	911102	326-324	150	O.p.
These last two flats are present on the same spur, and thus indicate a composite 330-foot platform.				
8. Long Down (M)	934098	330-321	650	A.q./O.p.
9. Long Down (M ?)	937107	332-321	230	M.t.
These two flats are on the same spur and separated by a remnant of the 345-foot platform (936100)				
10. (M)	939110	315-300	170	M.t.
11. Eartham (M)	940090	303	Summit	A.q.
12. The Plain (S)	951108	322-312	440	M.t./M.c-a.
This is situated on the spur leading north from Nore Hill. Near the hill the southern 150 yards of the flat lie at 312-314 feet O.D. To the north the slope increases slightly, but it is impossible to fix the northern limit exactly due to the thick scrub vegetation.				
13. Downs Farm (S)	037126	333-325	100	T.l.
14. Camp Hill (S)	042114	320-316	500	M.c-a.
15. (S)	061110	328	Col	M.c-a.
16. New Down (M)	061087	330-320	200	A.q.
17. Patching Hill (M)	082078	301-298	400	A.q.
18. Patching Hill (M)	079081	330-315	400	A.q.
These last two flats, separated by a break of slope, betray the compound nature of the 330-foot platform.				
19. Harrow Hill (M)	083090	326		O.p.
The elevation quoted refers to the forward edge as the back is a gradual increase of slope towards higher ground.				

Locality and Origin	Grid Reference	Elevation (Feet O.D.)	Length (Yards)	Stratum
20. (S)	119118	323	Col	I.l.
21. Mount Carvey (M)	141069	312-300	100	A.q.
22. The Nore (M)	160060	305	Summit	A.q.
23. Steep Down (M)	169069	330-308	250	O.p.
24. Lancing Ring (M ?)	178068	330-328	100	O.p.
25. Annington Hill (S)	179093	325-322	100	M.c-t.
26. Coombehead Barn (S)	183084	328	Summit	M.c-a.
27. Benfield Hill (M)	260079	308	Summit	
28. Pyecombe (S)	282129	330	Col	
29. (M)	294081	330-325	100	
30. (M)	295070	330-327	200	
The built-up nature of the area makes exact observation difficult.				
31. Falmer (S)	354089	302	Col	
32. Long Hill (S)	376096	327-322	350	
33. Cattle Hill (M)	352037	304-301	230	
The back is missing.				
34. (M)	366045	328-325	180	
35. (M)	372041	319-314	170	
36. Heathy Brow (S)	397053	330-328	250	
37. Southease Hill (S)	411040	316	Summit	
38. Telscombe Tye (S)	401032	330-300	700	
The forward edge has been slightly lowered.				
39. Snap Hill (M)	462040	332-320	500	
The back of the flat is missing.				
40. High and Over (M)	508011	318	Summit	O.p.
41. Alfriston (S)	512032	329-319	180	M.c-t.
42. Haven Brow (M)	532981	330-311	800	M.t.
43. Snap Hill (M)	541001	320-310	230	M.t.
44. Long Down (M)	577968	320-318	170	M.c-a.

The 290-foot platform.

1. Little Down (S)	967099	285-275	650	O.p.
This probably represents a former course of the Fairmile Bottom stream.				
2. Dale Park (S)	978098	276-273	150	O.p.
3. Madehurst (S)	984106	290-283	560	M.t./M.c-a.
A slight sag occurs in the middle of the flat.				
4. Houghton (S)	009113	301-295	290	M.c-a.
This is part of a former valley-floor of the Arun.				
5. Downs Farm (S)	035121	300-298	250	T.l.
This is also part of the 290-foot valley-floor of the Arun.				
6. Highdown Hill (M)	093044	269	Summit	A.q.
7. Tenants Hill (M)	149064	281-270	100	A.q.
8. Steep Down (S)	172079	290-283	600	M.c-a.
9. Lancing Hill (M ?)	188067	266	Summit	O.p.
10. Buckingham Barn (M)	219076	285-270	600	A.q.
The back has been eroded.				
11. Southwick Hill (M)	240072	290		
This small flattening is isolated by a sag to the north.				
12. Foredown Hill (M)	255073	288-280	170	
13. Benfield Hill (M)	258085	288-291	350	
At the southern end is a low eminence reaching 308 feet O.D.				
14. (S)	368089	262-258	180	
Owing to its low elevation and position in the Lewes Winterbourne valley, this flat may not be significant.				
15. Long Hill (M)	359042	277-274	100	
The back has been eroded.				
16. (M)	377027	278	Summit	

	Locality and Origin	Grid Reference	Elevation (Feet O.D.)	Length (Yards)	Stratum
17.	Southeast Hill (S)	404037	285-277	300	
18.	Southeast Hill (S)	412042	281-268	580	
	The overall length of the spur is 1600 yards, but the flats are separated by a low knoll reaching 316 feet O.D. (411040).				
19.	Mill Hill (S)	413056	287	Summit	
20.	Bullock Down (S)	414033	280	450	
	The elevation refers to the forward edge, as the back has been lowered.				
21.	(S)	431014	274-271	300	
	The back has been destroyed.				
22.	Rushy Hill (S ?)	432007	275-273	150	
	The back has been destroyed.				
23.	Mount Pleasant (S)	461025	264	Summit	
24.	Seaford Head (M)	497978	283	Summit	M.t.
	Although partly destroyed by the sea, the summit appears to be flat.				
25.	(S)	532001	257	Summit	M.t.
26.	Fore Down (S)	532019	299-278	170	M.c-t.
27.	(S)	537011	278-276	270	M.c-a.
	This may be a false flat formed by the convergence of the valleys to the east and west.				
28.	Friston Hill (S)	547993	292-287	260	M.t.
29.	Jevington (S)	565024	c. 290	Col	T.l.
30.	Long Down (M)	572966	273-269	170	M.c-a.

The 230-foot platform.

- Forest of Bere. The eastern part of the Forest of Bere is a slightly-dissected plateau cut across both Chalk and Tertiary strata. South of Idsworth House (730130) the ground flattens at about 230 feet O.D., this being well shown south of Woodhouse (723126). Taken in conjunction with Horsefoot Hill (715112), which reaches 232 feet O.D., this is the largest area of 230-foot plateau in the South Downs.
- Racton Monument (M) 777097 214 Summit A.q.
- Arundel Park (M) 010083 227-208 440 A.q.
- Wepham (S) 047083 224-210 200 A.q.
- Slonk Hill (M) 224067 221 Summit A.q.
- Dyke Road Park (M) 301059 229-222 200
- High View (S) 304087 219-216 300
- The back has been lowered to below 200 feet O.D.
- Round Hill (M) 316058 230 Summit
- Queens Park (M) 320048 230-222 300
- (S) 374087 212-207 150
- This, and the following four flats, form the dissected plateau south-west of Lewes, which has been described and photographed by Bull [4].
- (S) 382088 211
- The elevation refers to the forward edge as the slope flattens gradually.
- (S) 386087 216
- Again the back is merely a gradual flattening.
- (S) 388088 233-234 270
- The back has been destroyed by erosion.
- Jugg's Road (S) 392089 233-228 1000
- This flat is dissected into three rounded knolls.
- (S) 393076 217-204 180
- (S) 403109 230-229 330
- Beacon Hill (M) 364029 208 Summit
- Lodge Hill (S) 416026 232-224 860
- This flat is slightly dissected.
- Nore Down (S) 431018 207-203 300
- The back has been destroyed and some lowering of the flat has occurred.

Locality and Origin	Grid Reference	Elevation (Feet O.D.)	Length (Yards)	Stratum
20. Norton Hill (S)	464024	239-240	550	
This may be a false flat, due to the spur being undercut by Poverty Bottom to the east.				
21. South Hill (S)	503981	236-235	220	O.p.
22. South Hill (S)	504978	214		M.t.
This flattening is too gradual to enable a backward limit to be fixed : the elevation quoted refers to the forward edge.				
23. Exceat Hill (S)	525990	220-211	220	O.p.
The back has been destroyed by erosion.				
24. (S)	528001	232-230	200	M.t.
25. Belle Tout (S)	561957	228-225	120	M.t.

The 180-foot platform.

1. Warningcamp Hill (S)	050077	183-175	250	A.q.
2. Applesham Farm (S)	189074	180-170	400	M.c.a.
3. Lancing College (S)	192066	180-178	80	O.p.
4. Mill Hill (S ?)	212070	178-175	300	A.q.
5. South Heighton (S)	454034	182-172	470	
6. Ewe Down (S)	505001	190-177	440	O.p.

DISCUSSION

DR. A. J. BULL, congratulating Mr. Sparks upon the completion of his work on the erosion flats of the dip-slope of the South Downs, said that taken in conjunction with other researches it would help in the solution of the Pleistocene succession in this country.

Upon the question of the now dry valleys in between these erosion flats Mr. Sparks had expressed some opinions on which the speaker sought further information.

In discussing this problem it should not be forgotten that the South Downs could not be treated as if there had been only one glacial period, for the evidence was now definite that there had been a succession of such periods. Ice sheets had repeatedly spread over north and central Britain, and on at least one occasion had approached the position which was now London, and in consequence it was difficult to imagine that the Downs were not deeply affected by the cold. The shattering and contortions to be seen in the cliff sections between Black Rock and Rottingdean and at Birling Gap could only be ascribed to freeze-and-thaw conditions.

The main valleys and drainage lines were of course initiated before the cold came, and during the greater part of the Pleistocene the conditions must have had a general resemblance to the present, but often it was warmer. Such part of the Chalk surface as was exposed to the air above the dropping water-tables and was not protected by Clay-with-flints was subjected to surface solution only, while the running streams cut gorges and terraces as they were now doing at Wannock and below the Dyke. These conditions could not produce the broad and deep now dry valleys, which were so smooth that there was little trace of ordinary river action. The late Clement Reid thought that these spectacular valleys were cut by melt water from a copious snow cover at times when the chalk was rendered impermeable by being saturated with water and this being frozen. Although our climate was now mild, these conditions were actually achieved in February, 1940, when Lord Kennet of the Dene had an icy stream pass through his house from front to back. The evidence for repeated cold conditions in Britain comprised the occurrence of "warm" and "cold" faunas in the drift deposits, the records of ice sheets, corries throughout the country, the various contorted drifts, and the shattering of chalk near the surface. On this evidence alone without that of the dry valleys themselves it became reasonable

to assume that during periglacial conditions the chalk of the Downs was impermeable and supported streams. The speaker understood that Mr. Sparks stated in his paper that the "melt-water hypothesis seems not only unnecessary but also inadequate to explain the origin of the dry valleys" and then added that "such minor trenches as the Devil's Dyke and the Coombe at Lewes may be due to melt-water"; these statements were, to the speaker's mind, contradictory and required more explanation. These two "minor trenches" were deeply cut into the Downs, and to cut them required a localised and copious supply of water high up on the hills. This could only have been melt water from snow, with a thick snow cover protecting the higher parts. If this were admitted, then Mr. Sparks should explain why the same severe weather conditions did not apply to the dry valleys only a few yards distant.

While many dry valleys now breached the escarpment in wind-gaps or lowered the edge, great numbers of them both in the North and the South Downs terminated just behind the escarpment edge, some behind a slight lowering of it and others behind culminations of the escarpment as if they had been added to an earlier drainage system. One such example was the deeply cut dry valley that headed behind Chanctonbury Ring. In the North Downs they sometimes headed against masses of Clay-with-flints as Mr. A. G. Bell had pointed out.

Dr. Bull pointed out that on Fagg's hypothesis the dry valleys were initiated and cut by water from springs on the dip-slope, and to secure the necessary high water-table it was imagined that the escarpment was further forward than at present. It followed that springs were supposed to have cut back their heads to such positions that when much later the escarpment receded, the heads of the dry valleys found themselves just behind the new position of the escarpment. It would be interesting if Mr. Sparks would explain how this was possible.

Two matters that Mr. Sparks did not seem to have mentioned were of fundamental importance to his arguments; the corries cut into the face of the escarpment at Eastbourne and other places and the 200-foot platform (Amber-sham Terrace or Winter Hill Terrace). The armchair shaped corries were land forms that could only have been produced by snow and ice, and no doubt took up their functions during each succeeding cold period. By comparison with Iceland and other countries they indicated a severe climate.

In the South Downs the positions of the remnants of the 200-foot platform as mapped by Kirkaldy and the speaker entirely negated the possibility of any marked recession of the Chalk escarpment since "200-foot" time. This rock-cut terrace was still close up against the escarpment for many miles, and therefore there had been hardly any recession of that escarpment during at least half of Pleistocene time. Mr. Sparks should explain how Fagg's or any other hypothesis could account for the erosion of valleys that were during the interglacials and even in "200-foot" time hundreds of feet above any possible water-table.

The various stillstands of sea-level must each have produced in the South Down valleys gorges or terraces just as they were now being produced at Wanknock and other places as determined by the water-table. This occurred repeatedly under warm conditions, and was followed by a fall in sea-level, so that the old river effects would be left in the air. These could be obliterated and the valleys widened and deepened under freeze-and-thaw conditions with melt water to sweep away the debris to the low sea-level that accompanied glacial periods. As Mr. Sparks denied that freeze-and-thaw with its accompanying melt water had been an agent in this, he must therefore explain why there were not in these valleys remnants of the old terraces and channels.

Another point on which the speaker said he would like enlightenment was how, in places for several miles, the edge of the escarpment had been preserved from being cut by the heads of the now-dry valleys immediately behind it, if it were not by a heavy snow cover.

These dry Chalk valleys were characteristic of the Chalk outcrop in several counties, and any explanation of their origin must account for their production under all the conditions in which they occurred.

Dr. Bull trusted that in his earlier remarks he had made it clear that he welcomed the work Mr. Sparks had carried out on the dip-slope of the South Downs, and that it was merely on subsidiary matters that he was seeking more information.

MR. W. V. LEWIS joined previous speakers in congratulating Mr. Sparks on the work he had done, and on the admirable presentation of his findings. Any comments or criticisms Mr. Lewis had to offer mainly concerned matters of detail.

First he would have liked to have seen photographs and cross-sections of the landforms Mr. Sparks had described. This would have enabled hearers to judge his conclusions more readily. As plotted on the diagrams the platform fragments were most striking, and certainly appeared to demonstrate convincingly some, at least, of the series of levels recognised by Mr. Sparks.

Concerning the explanation of the dry valleys Mr. Lewis was less happy. He considered that on general grounds it seemed unlikely that a closely-knit series of valleys would owe its origin to a halting downward movement; alternations of downcutting and relative stagnation resulting from such an intermittent fall in base level would probably not, in his opinion, produce such apparently unified results in these valleys.

The thesis that the upper parts of these dip slope dry valleys were cut when the sea level was high enough to cause water to flow in them appeared to the speaker to ignore the fact that these valleys had today gradients considerably steeper than that of the water-table beneath them. He referred to a sectional diagram of the South Downs taken from Halton Thomson's paper "Hydrological conditions in the Chalk at Compton, W. Sussex" (Inst. of Water Engineers, 1921) to illustrate this fact. On this diagram the lowest level of saturation in the Upper Chalk was seen to slope far less steeply than the valley-floor directly above it, while even the steeper gradient of the highest saturation level was distinctly less than that of the corresponding part of the valley floor. Mr. Sparks had assumed that the upper parts of these valleys had not altered since well back in the Pliocene when the sea-level, together with the water-table, fell. Presumably therefore the relief of the Downs then was much as it was at the present time, except for elevation relative to the sea. The occasional outbreaks of the springs at Compton during very wet periods, marked by the highest saturation level on Halton Thomson's figure, might be expected to lead to water-table conditions not very dissimilar from those produced when the sea-level was approximately 300 feet above that of today.

Mr. Lewis enquired why Mr. Sparks assumed that the water-table then followed a gradient steeper even than during times of exceptional floods today in order to reach the floors of these valleys. The gradient of the water-table upstream from the springs was a function of percolation and the rate of seepage through joints and cracks in the chalk. It could only be altered by varying one or both of these factors. The most likely way of increasing the gradient of the water-table above the springs would be to increase percolation by increasing rainfall and—or—the rate of runoff from melting snows during a spring thaw—in other words to reproduce the very conditions that were known to have existed during much of the Pleistocene. Like Dr. Bull, Mr. Lewis could not conceive that the severe climatic conditions of the Pleistocene, acting on these Downs when they were largely bare of vegetation, could have failed to leave their mark on the area.

He considered that it was very difficult to envisage the water-table rising to the floor of the dry valleys without appealing to climatic change; but it was a far greater problem to bring the water-table right to the surface of the dip slope for the initiation of valley cutting.

Any substantial change in the water-table due to the recession of the escarpment was unlikely, because such a recession would make it still harder to account for the few deep-cut escarpment dry valleys such as the Devil's Dyke at Poynings. Furthermore, these valleys were far too steep-sided to have survived the

Pleistocene in their present form. Mr. Sparks' whole thesis seemed to be that the old features such as benches in the sides of the river-valleys were often fairly well preserved. His thesis should therefore discount any hypothesis of marked erosion away from the streams themselves, such as rapid scarp recession.

The speaker pointed out that in the South Downs north of Chichester Mr. Fagg's hypothesis of lowering of the water-table by escarpment recession with the consequent lowering of the level of the Gault outcrop, lost much of its force, because the dip of the Gault flattened out in the plain immediately north of the escarpment. It could therefore have caused relatively little rise in the level of the water-table, even long ago when the scarp was several miles further to the north.

MR. B. S. GOSSLING said that anyone who knew the South Downs might well envy the well-spent and well-rewarded energy that the author had found for unravelling so complex a problem. Complex it was almost bound to be, seeing that the Chalk had such a way of preserving traces of events that had disturbed its surface—from the Eocene-Miocene planations to the bombholes of the recent abnormal precipitation. Such superposition must make it difficult to establish the effects of any particular agency, but on the other hand if there were something which might or ought to have happened one could reasonably expect to find traces of it somewhere on the Chalk surface.

The author's knowledge of these things must now be comprehensive. He must have observed many other things while surveying his platforms and particularly perhaps the valleys dissecting them. So the speaker was encouraged to ask the author's opinion of a striking and peculiar feature of the inner scenery of the South Downs, namely, the frequent occurrence of valleys, mainly tributary to the main gaps, which started near an escarpment, and after a short stretch of a mile or so in the expected southerly direction, took the form of a smooth curve, sweeping round through a right-angle, or perhaps more than that, so that they often approached the main valley upstream. The outer side of the curve was smooth and very steep, sometimes as steep as chalk could well be. To the speaker there was something almost majestic in its continuity, but majestic or not, it presented a very intriguing enigma. There were many such valleys all along the dip slope to the Hampshire border, and beyond, some 20 of them at least, and he knew a number of them. He must confess that, unlike the author, he had to be content with making his recent studies on Ordnance maps: however, the valleys were well over 100 feet deep and the run of the contours showed them plainly.

Their main characteristics could be matched on other southward dip slopes, but it was in the South Downs that they seemed to be most fully developed. In the South Downs these curving sweeps had a marked eastward bias, five out of six of them sweeping from south to east or north of east. One of them, west of Alfriston, turned through a full 180° from south-west to north-east, and a larger valley concentric with it almost as much. Again, a valley east of Rottingdean seemed to have found its southward course unstable, and made a marked leg to the east before going south again to the sea. With so large a total change of direction simple working down the dip could not be the whole story and the speaker was led to look for something else, and to put his speculations in the form of a highly imaginary description of the scene in one phase of the denudation. In certain suitable phases of the Ice Age a smoothly curving river-cliff might have been seen, apparently made of solid limestone, actually deeply frozen chalk, dipping mainly inwards, and with little melt water coming down it. This cliff would have been facing towards the northern quadrant and usually rather towards the east. At the foot of it would have been an intermittent stream eroding its base much as the sea eroded a marine cliff. The stream was copiously fed in proper seasons with melt water from the broad catchment of the inner slope, where the dip helped the removal of chalk in dissecting the boulders and gullies we generally now saw disposed radially to the main curve. The inner slope would have had little or no vegetation to protect it, also it faced south and

usually rather west towards the afternoon sun and the warmer winds. The outer slope, contrariwise, would have got a glimpse, if that, of the morning sun, at grazing incidence, and it faced usually north-east towards the winds of the polar anticyclone, if there was one. That was the speaker's picture of a particular phase of the denudation. It would have been a transient phase, though it might have been repeated, but the conditions would have been so favourable to rapid denudation that it should have left its mark on the present form of the valleys.

The speaker said that he wished he felt more sure that the various factors added up to an eastward bias, but on the whole he thought they did. Steeper eastward facing slopes did seem to be common in the main river gaps, and they did occur also in the straight obsequent valleys running north into the upper Lavant. How much of the recent denudation could be accounted for in this way he could not suggest. Other things would have happened before or since and he had been describing only one possible significant phase : a sort of still in the continuous film of denudation, but the form of the valleys was a fact inviting explanation.

MR. C. C. FAGG added his congratulations to the author on the completion and lucid exposition of so remarkable a piece of work. He had recently had the privilege, with other members of the Association, of going over some of the ground with Mr. Sparks and had been amazed at the number of separate platforms he had identified on the dip-slopes of the South Downs. The dip-slopes of the North Downs, so far as he knew, had not been subjected to so careful an examination, but he doubted whether any similar series of platforms would emerge from such an examination. It was noteworthy, however, that four of the most clearly indicated platforms in Mr. Sparks' ingenious diagram (Fig. 27), namely, 430, 330, 230 and 180 feet are approximately 30 feet higher than the four main terraces in the basins of the Mole and other northern rivers.

He was naturally in agreement with the author's views on the origin of the dry valleys. He was at the present time engaged in an investigation of the coombes and other features of the Chalk escarpment all round the Weald. These are found to be intimately connected with the river and wind gaps and with former Chalk valleys beyond the present escarpment. For instance, until the Devil's Dyke was cut down to 400 feet above present sea-level the stream that flowed in it was a tributary of the river flowing through Saddlescombe southwards towards Brighton. Referring to the author's map of the upper Lavant (Fig. 33) he pointed out that the mass of chalk bounded by the Cocking and East Dean valleys was closely comparable to Mount Caburn, at the entrance to the Ouse gap, at an earlier stage. The coombes in the escarpment on the south side of the Glynde river, between Beddingham and Firle, obviously originated as tributaries of that river. Similarly, if the mass of chalk to the north of the East Dean valley had reached the stage of being an outlier, like Mount Caburn, before the valley had been left dry, then the southern side of the valley would have become the escarpment with ready-made coombes and perhaps a remnant of a 200-foot gravel terrace on its face. Thus the features of the escarpment could not be rightly understood without reference to the gaps and the internal dry valley systems and *vice versa*.

He agreed with Prof. Wooldridge that it was unwise to apply the term " sub-sequent " to the strike valleys in the Chalk. For the rest Mr. Sparks' paper was packed with so many suggestions and points of interest that he looked forward to studying it carefully when it was available in print.

DR. J. F. KIRKALDY said that he had heard much about all stages of this work and he had been particularly glad at a recent Field Meeting to have the opportunity of seeing Mr. Sparks' erosion surfaces on both sides of the Adur gap. The speaker was fully prepared to accept the surfaces then demonstrated as of real significance.

Another side of Mr. Sparks' work was his careful investigation of the accuracy

of aneroid determinations. Having been a Meteorological Officer during the War, Mr. Sparks had made a very thorough investigation of the meteorological factors which caused microfluctuations of atmospheric pressure. The speaker looked forward to a further contribution from Mr. Sparks setting forth those meteorological conditions under which an aneroid could be used as a precision instrument.

MR. B. H. FARMER congratulated Mr. Sparks on the quality of his fieldwork and on his excellent presentation of his paper. There were two points on which he would like to comment briefly. In the first place, he endorsed Mr. Evans' plea that, if time permitted, a little might be heard from Mr. Sparks about his aneroid surveying technique. The aneroid had a reputation for fickleness, and few would care to use it where accuracy was important; yet Mr. Sparks had confidently used it to distinguish a very closely-spaced set of platforms, two of them only 15 feet apart. The speaker did not boggle at the notion of a multiplicity of Plio-Pleistocene surfaces, since so much work in so many places appeared to be in favour of it, and, above all, he did not suggest that Mr. Sparks' confidence was rash or unjustified; but some indication of his technique would be welcome.

Secondly, the speaker wished to make a point, very briefly, about dry valleys of the type exemplified by the Devil's Dyke. He did not claim to know the ground very well, but this type of dry valley appeared to be similar in aspect and form to the obsequent dry valleys of the Pegsdon area, near Hitchin, which Mr. Vaughan Lewis had explained in terms of headward sapping by springs during periods of high water-table. Mr. Lewis' work might not yet be known to all members present. It might be added that spring-sapping appeared also to be a major factor in obsequent development in the Cotswolds. Headward sapping, it seemed to the speaker, was a better explanation of the marked amphitheatre-like head of valleys of the Devil's Dyke type than any of the other hypotheses which had been aired during the discussion; and could easily explain the capture of earlier drainage by the Dyke which one speaker had mentioned.

DR. M. M. SWEETING said she also wished to add her congratulations to the author on a stimulating paper. She felt that the recognition in this country of such erosion platforms as described by the author had been far too long delayed; she had no hesitation in accepting their existence in the area discussed in the paper though she would have liked to have seen more of the geological evidence. She would also like to know if any longitudinal profiles of the dry valleys had been investigated and if those profiles could be used to show a relationship between the dry valleys and the platforms recognised in the area. It was clear that if there was such a relationship, the problem of the origin of the dry valleys of the South Downs was solved.

MR. W. G. V. BALCHIN said that, in company with other speakers in the discussion, he would first like to express his admiration for the persistence and thoroughness with which Mr. Sparks had carried out a most interesting investigation. A multiplicity of surfaces such as had been demonstrated in the Chalk was perhaps only to be expected with a falling sea-level; in rocks more resistant than chalk minor stillstands would perhaps go unrecorded whilst in other less resistant rocks later sub-aerial erosion might well destroy the record.

He wished to draw attention to two general points. Whilst the term "flats" would be understood by those who had worked in this field of research, it might be confusing to the newcomer; for extensive surfaces, either sub-aerial or submarine, were frequently far from flat. "Erosion surface" might be acceptable for general usage with "platform of marine denudation" and "sub-aerial surface" for the particular case.

The ingenious diagram which Mr. Sparks had prepared to show the height range of the erosion surfaces overcame the problem of presenting the results, but the speaker would like to see an accurate distribution map of the surfaces

within the area considered ; the sub-aerial being distinguished where possible from the submarine and the trend of the old coastlines also being indicated where feasible. Maps of that kind which could not be reproduced easily in the *Proceedings* could perhaps be retained by the Association for future research workers. As further investigation of this nature proceeded it should also become possible before long for the geographer to examine the relationship between land use and erosion surfaces, and for this type of enquiry maps showing the spatial distribution of the surfaces were of course essential.

Professor S. W. Wooldridge and Mr. Percy Evans also spoke.

MR. J. F. N. GREEN'S communication, printed below, was read before the discussion took place.

I have had the privilege of reading Mr. Sparks' paper and am glad to express my appreciation of a valuable series of observations in a terrain, the Chalk, which in my experience is difficult country to investigate. His ingenious chart of the height, range and position of the flats gives a conspectus of a mass of details, otherwise not easy to grasp.

I feel that I must differ from the author on one question of interpretation. He writes of a group of flats as undoubtedly marine since explanation as high terraces of a longitudinal stream, such as an extended Frome-Solent, would require the platforms to fall eastward, whereas each is horizontal.

It was in the Frome-Solent that I determined horizontal segments in seaward parts of its terraces (*Proc. Geol. Assoc.* 57, 1946, p. 92). There the Boyn Hill terrace was mapped horizontally for 20 miles; it probably extends at the same height for 20 miles more. There was nothing unexpected in this. Pocock pointed out in 1902 (*Summ. Prog. Geol. Surv.*) that the 100-foot terrace of the Thames was horizontal for at least 40 miles. In a paper on the river Dart, which the Association has kindly accepted,¹ I give some particulars of the local horizontal segments of the 430-foot, Sicilian and other terraces. They are small compared with the horizontal terraces of the Potomac (Hickok, *Amer. Journ. Sci.*, 1933, 25, p. 112).

Such segments extend far up tributaries. The horizontal part of the Frome-Solent Sicilian terrace goes up the Avon past Salisbury, at least 25 miles. Therefore, whether the author's marine group is to be referred to open sea or to a horizontal segment, the condition may be expected to spread far up the Chalk rivers, and the distinction between subaerial and marine platforms becomes doubtful.

As grounds for classifying certain flats as subaerial, he says that oscillations of sea-level would be necessary to flood them. But, as a rule, no change of sea-level, other than tidal oscillation, is required to produce a horizontal segment. The author holds too that, even if the areas in question were flooded, the fetch would have been far too limited for the formation of waves capable of marine planation. I suggest that some evidence is desirable in support of this generalisation. Observations in the hard Palaeozoic volcanics, several miles up the estuary of the river Dart, find notches 15 feet deep, which have been cut since the post-Roman rise of sea-level. The high terraces of the South Down valleys must have involved vastly longer periods and offer longer fetches. Lateral erosion by meanders has also to be allowed for.

If the distinction between subaerial and marine platforms breaks down, the 475-foot platform would be more correctly termed a 490-foot, or 495-foot platform.

The evidence for a separate platform near 380 feet is important. It is probable that search will discover its equivalent in Devon and Cornwall between the more strongly marked 430-foot and Sicilian levels. My own knowledge of that range of height is very inadequate.

¹ "The History of the River Dart," *Proc. Geol. Assoc.*, 60, 1949, pp. 105-24.

The author, in reply, thanked the members for their kind reception of the paper and was delighted that his remarks on dry Chalk valleys had aroused such discussion. He wished to clarify his position by stating that he thought the melt-water hypothesis unnecessary to explain the origin but necessary to explain the modified form of some of the valleys—the antithesis being between origin and modification—and apologised if he had not made this sufficiently clear. He was dealing solely with the dry valleys of the South Downs and was not attempting to formulate a hypothesis of origin of universal applicability. He was acquainted with the results of Mr. Lewis' work on the Pegsdon valleys, mentioned by Mr. Farmer, and fully realised the difficulty of applying Fagg's hypothesis to the origin of these particular valleys.

Many of Dr. Bull's queries would be found to be dealt with in the text of the paper. The author thoroughly agreed with Dr. Bull's statement that the "main valleys and drainage lines were of course initiated before the cold came." Dr. Bull's charge of inconsistency in the author's statement concerning the minor gashes in the escarpment would be found to be unnecessary in view of the precise wording used in the paper. The author agreed with Dr. Bull that a hypothesis of origin should, if possible, explain all dry Chalk valleys, but considered this one of the objections to the melt-water hypothesis, a point made 60 years ago by Topley in the discussion on Clement Reid's original paper. The disagreement between Dr. Bull and the author really concerned only the origin of the dry valleys, as the author had no wish to deny the occurrence of cold conditions, which had left their mark in the corries, the Coombe Rock and the modified form of some of the dry valleys.

In reply to Mr. Lewis, the author stated that he had made no assumptions of a formerly steeper water-table gradient in the Chalk, but had shown, by a consideration of the total geography of the early stages, that the water-table, upheld by sea-level and the level of the Gault outcrop, had been at or very near the surface. Had this not been so, it was extremely difficult to see how the major transverse drainage of the Downs could have occurred. The author found himself unable to agree with Mr. Lewis' last statement as he believed, although without precise data at hand, that, when the Chalk escarpment ran through Midhurst, i.e., three miles north of its present position, the Gault outcrop must have been approximately at its early Pliocene level.

Mr. Gossling had commented upon an extremely interesting type of valley, which, in the South Downs, usually had its steep concave side capped by *A. quadratus* Chalk (Brydone's definition). The author considered these to be valleys of incipient subsequent type, comparable on a smaller scale with the valleys which he believed to have been responsible for the original creation of the secondary escarpment. Their present smooth curves with remarkable undercut cliffs were probably due to modification by melt-water. The author was not sure that the valleys showed such a marked tendency to sweep eastwards, most of them occurring in pairs, one of which turned to the east and the other to the west, e.g., near Eartham, Clapham, and on either side of the Cuckmere gap near Alfriston.

Mr. Fagg's observation that the Northern Weald platforms differed in elevation from those of the South Downs was to be expected, as there could be no direct correlation between the former, which were subaerial and at a considerable distance from the shorelines of the periods concerned, and the latter, which were marine. The author in the paper had carefully reviewed the structure of the upper Lavant area. Strictly speaking the stream occupying the Dean Valley axis should be termed "insequent," as the author admitted that he had been unable to find any obvious cause of its initiation, this being one of the original meanings attached to the term "insequent" by W. M. Davis. Further work would, perhaps, demonstrate that it was really a subsequent stream.

In reply to Dr. Sweeting, the author stated that he had not examined in detail the long profiles of the dry valleys. He thought that modification by melt-water and cultivation must have obliterated much valuable evidence and agreed that, should evidence of any of the planations be found in the dry valleys,

it would prove that the valleys could not have been originated by melt-water since the date of the earliest platform preserved therein. But, as the relation between the cold periods and the planations was largely unknown, there was still a possibility, unless evidence of all planations from the 475-foot onwards was found—and the author considered this highly unlikely—that the valleys might have been initiated by melt-water in an early cold phase.

The author, in reply to Mr. Farmer and Mr. Evans, said that the aneroid surveying technique was really the subject of another paper, which he hoped to write in the near future.

Finally, in reply to Mr. Green, the author wished to state that he had read with interest of the horizontal segments present on the Hampshire and South Devon river terraces. While deferring to Mr. Green's extensive and original knowledge of longitudinal profiles, the author could not see, on general grounds, how a river could produce an eroded flat surface 55 miles in length, especially as the terraces of the tributaries of that hypothetical river showed apparent rises a short distance upstream. With regard to the effects of fetch on wave-planation in certain restricted areas, the author admitted this to be a personal opinion, but hastened to add that the subaerial origin] of the flats in question did not depend upon this opinion, as the rise upstream of these flats demonstrated their subaerial origin.

THE TRIMINGHAM CHALK

By J. E. SAINTY, B.Sc.

[Received 3rd February, 1949]

SHORTLY before the outbreak of war in 1939 a sweeping north-westerly gale cleared away the sand which usually more or less covers the chalk on the foreshore at Trimingham, Norfolk, and from the cliff top I was able to look down on a complete plan of the exposure. I communicated the news at once to Mr. Hallam Ashley, and within 48 hours he had obtained the photograph which with his consent is here reproduced. Publication of the photograph seems to call for a brief summary of the history of work on the Trimingham Chalk.

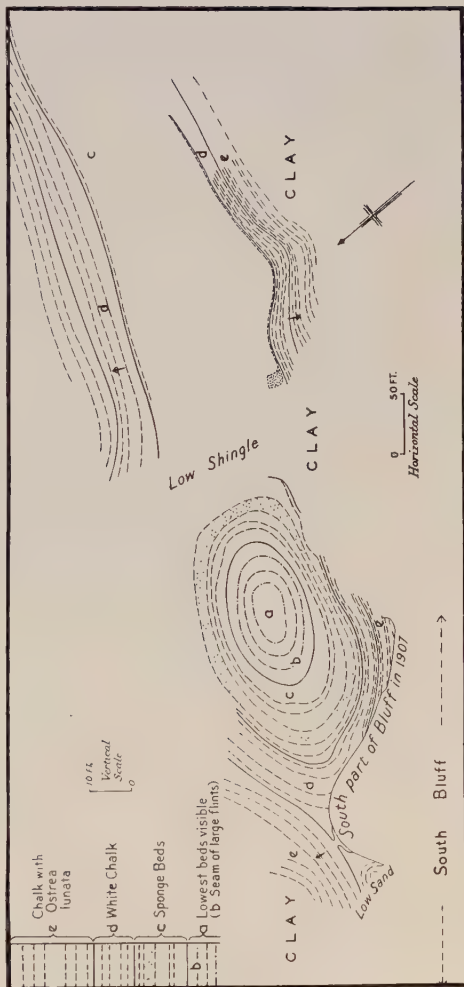
The Upper Chalk of the *Belemnitella mucronata* zone first appears on the North Norfolk Coast at Weybourne, forming a cliff about 20 feet above high-water mark. The surface of the chalk, which is dipping eastwards, reaches beach level just beyond Sheringham and is below sea-level at Cromer. From Cromer to the east of Overstrand, the only chalk visible is in the form of erratics in the cliff glacial beds, until at Trimingham, almost on the Mundesley border, a single chalk bluff is visible in the cliff, and at low tide a stretch of chalk is seen below the beach.

The chalk exposed at Trimingham early attracted attention, both from its isolated position, apparently unconnected with the main Upper Chalk, and from its very disturbed nature. In 1833 Samuel Woodward wrote,* "The Chalk appears in two isolated disrupted masses and presents some specimens of fossils peculiar to it." In 1835 Lyell gave an "imaginary section of the outline of the surface of the subjacent chalk such as might explain the relation of those protruded masses, three of which appear in the cliffs near Trimingham, and which some geologists have too hastily assumed to be unconnected with the great mass of chalk below." In 1876 Barrois mentioned this chalk "as belonging to the highest stage which approximates to the Danian of D'Orbigny." In 1904 Jukes-Browne stated, "The highest chalk in England is found on the coast of Norfolk near Trimingham and Mundesley, and as this contains a special fauna of its own we propose to separate it as the zone of *Ostrea lunata*. . . . It includes some species which are common in the chalk of Rugen and Maestricht. The flints which they contain also differ from those of the Norwich chalk, being for the most part small and having a rough outer surface; many are hollow and are filled with a greyish chalk, which is rich in sponge spicules, foraminiferas and other small fossils. . . . *Ostrea lunata* abounds, other characteristic fossils are: *Pecten serratus*, *Galerites abbreviatus*, *Trochosmilia cornucopiae*, *Thecidium vermi-*

* For list of References, see p. 218.



A. Trimingham foreshore at low tide in August, 1939, showing dome and antiline in *Ostrea lunata* Chalk after the sand had been swept off by a north-westerly gale. Photograph taken from top of 200-ft. cliff by Hallam Ashley.



B. Map of Chalk outcropping on Trimingham foreshore in 1907. Apart from small patches of clay and shingle the marginal cover deposit was sand. After Brydone, 1908.

culare, *Terebratulina Gesei* and the large typical form of *T. gracilis* which is not found elsewhere in England. . . . The chalk contains bands of flints at distances of from two to three feet apart. Some are hard, black and compact, but the majority are only half silicified, being hollow or partly filled with a grey chalky matter, which is gritty to the touch and is full of sponge spicules and minute organisms." In 1900 R. M. Brydone dealt with "the Stratigraphy and Fauna of the Trimingham Chalk," adding in 1901 "Further Notes. . . ." which contained a valuable series of photographs, tracing the extent of the erosion during those years, and in 1908 he dealt with the "Subdivisions of the Chalk of Trimingham," illustrated with Plates in colour showing the measured plan of the chalk exposed on the shore. On Plate 7, Fig. B is reproduced the portion of Brydone's plan which is the subject of Mr. Hallam Ashley's photograph and a comparison of the two provides a striking tribute to the accuracy of Brydone's mapping.

When the Geologists' Association visited the area in 1923 Boswell reproduced a photograph of "Bluffs in Lunata Chalk and Overlying Glacial Deposits, Trimingham." The free standing pinnacle disappeared within a few years but a remnant of the bluff still stands in the cliff face. At present this spot is the centre of an uncleared mine-field and has been declared a danger zone by the military authorities, though the exposures below tide mark, as shown on the photograph, are accessible by boat or, with some risk, at low tide. Boswell agrees with Lyell, "The Chalk is clearly much disturbed, presumably by glacial action, nevertheless the masses do not appear to be transported blocks. Moreover, apart from any question of minor disturbances, the outcrop of the zone is here approximately in its natural and expected position with regard to the other zones in Norfolk. From the dip and position of the outcrop the zone is estimated to be 70 to 80 feet thick where it is covered by Eocene deposits. This figure is in agreement with that obtained by Dr. W. K. Spencer from a study of the Asteroid fauna." Brydone 1908, describes the exposure shown in the photograph as follows :

"This block forms an east-and-west anticline. The lowest beds exposed in it are four beds of White Chalk, appearing in a narrow oval close to the bluff, which are marked (a). The line of flint (b) which separates the upper two of these beds is readily recognisable by the great size of the individual flints of which it is formed, these being far larger than the flints in any other line of flint seen at Trimingham. Fossils are fairly abundant. . . . This fact strongly suggests that these beds are very near the base of the zone. The beds rest above those just described as designated by me as 'Sponge Beds' (c). They are about 12 feet thick, strongly yellow in colour and more or less hardened, sometimes so much so that a knife makes practically no impression. . . . The next

set of beds (d) about 9 feet thick consist of White Chalk without *O. lunata*. . . . The next set of beds with *O. lunata* is the highest of this sequence yet known." Higher series of beds occur in the bluff at the foot of the cliff.

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FIELD MEETING IN THE NORTH CHILTERN HILLS AND AYLESBURY DISTRICT

Saturday, 10th April, 1948

Report by the Directors : A. Morley Davies and Vernon Wilson

[Received 19th January, 1949]

THIS excursion was made from London and back again by coach which left South Kensington with 37 members at 9.5 a.m. As the coach traversed the gentle slope of Exhibition Road to High Street it was pointed out that the adjacent Kensington Gardens marked the position of the Taplow Terrace. The route westward through Shepherd's Bush and along Western Avenue by Northolt Aerodrome lay over the London Clay, the surface of which is diversified by variable thicknesses of superficial deposits.

Near Uxbridge the broad flats of the River Colne were reached ; most of the drainage from the area to be visited during the day's excursion flows into this tributary of the Thames. Here too, the route left the London Clay basin and in ascending Denham Hill the coach passed on to Reading Beds which form large areas of the southern slopes of the Chiltern Hills. These beds are rarely seen hereabouts as they are much obscured by overlying gravels and drift clay.

Just over a mile farther on, at Tatling End, the route descended into the Misbourne Valley which was followed to Amersham where Dr. Davies joined the coach. The vicissitudes of the Misbourne stream, which, after three or four years' disappearance, had recently been flowing again, were explained *en route*. At Great Missenden the road to Butler's Cross was taken and at Hampden Bottom the party had a fine view of Hampden House and the origin of the avenue with its two small Pepper-pot Lodges was explained by Dr. Davies. Farther on, Chequers Court, the official residence of the Prime Minister, was pointed out. At Butler's Cross the party reached the northern edge of the Chilterns and passed off the Chalk across the broad flat outcrop of the Gault towards Aylesbury. On the outskirts of the town five members of the Buckinghamshire Archaeological Society joined the party and, at the suggestion of Dr. K. P. Oakley, a short diversion was made to the Southcourt Estate where, in temporary excavations for new roads and houses, the following section was made out :—

		Feet
Portlandian	Rubbly limestones with <i>Protocardia dissimilis</i> , <i>Astarte</i> sp., <i>Trigonia</i> sp. and perisphinctids ...	5
	Glauconitic Sands, seen to	3
Kimmeridgian	Hartwell Clay below (not seen)	

The thicknesses of the Portland deposits given above are only a small part, near the base, of these rocks in the neighbourhood.

The party next visited Messrs. Webster and Cannon's brickyard in Aylesbury, on the north side of the Birtton Road, where the Hartwell Clay and overlying sandy pebble bed are exposed. About eight feet of the clay was visible and specimens of *Cucullaea* sp., *Astarte* sp., *Protocardia* sp., *Exogyra* spp., and *Perisphinctes* sp. (sensu lato) were found. The two feet of overlying pebbly sand yielded small pebbles of quartz, dark chert and black lydite and fragments of internal moulds of small ammonites.

The next stop was at the famous Bugle Pit at Hartwell, two miles south-west of Aylesbury. Though the section is now in a neglected condition, part of it had been recently excavated by Dr. Wilson and it was possible to examine most of the beds detailed in earlier excursion accounts by Dr. Davies (1897, 1912 and 1934).^{*} Dr. Wilson also pointed out the position of a stromatolitic algal band which he had recently discovered at the top of the section and specimens were collected. Lunch was taken at the Bugle Inn.

To the west of Hartwell the ground rises gradually on to the outlier of Aptian Sands on Purbeck Beds on which stands the village of Stone. These white sands were seen in the large pit worked by Messrs. Joseph Arnold and Sons on the north side of the village and such interesting features as the clay galls, iron staining, variety of small pebbles and the intricate patterns of cross-bedding were all examined and discussed by the members. At the next village, Dinton, the members alighted to admire the Norman (twelfth century) arch and tympanum over the main entrance to the church and the old stocks preserved on the small village green.

From this point the party travelled back towards the Chilterns, the principal features of which were discussed *en route*, until Ascott was reached. At the large quarry in the Chalk on the hillside near Warren Barn the following section was examined :—

	Feet
Middle Chalk	
3. Melbourn Rock	10
Lower Chalk	
2. <i>Actinocamax plenus</i> marls	9 inches to 3½
erosion surface	
1. White and grey chalk of the <i>Holaster subglobosus</i> zone	19 to 20½

The extent of the local erosion below the *plenus* marls amounts to 20 to 30 feet of white chalk which makes up this zone elsewhere. A short distance through Monks Risborough brought the members to Whiteleaf Cross hill where Dr. Davies gave an account of this Cross and the similar one at Bledlow farther west.

Towards the top of the hill about 15 feet of the Upper Chalk (*cortestudinarium* zone) was examined in a roadside quarry. The zone fossil, *Micraster cortestudinarium*, *Ventriculites* sp., and other fossils were collected.

^{*} For list of References, see p. 221.

After a pleasant devious tour through the wooded Chilterns the party arrived at the Milton Guest House, Chalfont St. Giles, where tea was served. During this interval there was an opportunity for members to visit the small historic cottage which was Milton's home for some years. Before the coach moved off to return to London, the President, Mr. Ernest S. Brown, expressed the thanks of the party to the Directors for a pleasant day's programme.

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1912. ———. *Proc. Geol. Assoc.*, 23, pp. 254-6.
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The above reports contain other useful references.

FIELD MEETING IN THE EPPING FOREST DISTRICT

Sunday, 9th May, 1948

Report by the Director : John F. Hayward, Ph.D., M.Sc., F.G.S.

[Received 13th January, 1949]

A PARTY of about 30 gathered at Chingford Station, whence they walked to the nearby top of Pole Hill, Chingford. At 300 feet O.D. this, the highest point in the neighbourhood, is marked by a small outlier of Claygate Beds, formerly worked for brickmaking. The Director pointed out geological features of the Lea Valley and drew attention to the fact that it was here that a very old friend of the Association's had first become interested in London Clay faunas (Wrigley, A., 1915, see below).

The party then walked to Yardley Hill where, on the 200 foot erosion platform (Wooldridge, S. W., 1928, etc.) patches of Chalky Boulder Clay were investigated. Among other erratics was discovered a large piece of Liassic limestone with characteristic fossils. Taking advantage of the good views of Lea Valley scenery, the Director discussed the various theories of the history of the Thames and Lea according to Sherlock (1924), Wooldridge (1938, etc.) and Warren (1942-3).

After lunch, which was eaten near "The Owl," the members ascended the slopes of the High Beach outlier, noticing the change in vegetation from Oak wood (typical of the London Clay), through Beech wood (Claygate Beds) to the Birch woods on the higher ground occupied by Bagshot Sands and Pebble Gravel.

From High Beach the Epping Road was followed as far as the Wake Arms, where Boulder Clay, so far unmapped, was exposed in wartime anti-tank ditches (Warren, S. H., 1942-3). The chief erratics discovered were unworn flints and chalk fragments. From here, those members who desired walked to Ambresbury Banks, an ancient encampment which the Director linked in his closing remarks with early habitations in the Lea Valley.

After the President had thanked the Director, the party proceeded to Woodford Wells for tea, and then left for London.

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FIELD MEETING AT FOLKESTONE AND SANDLING

Sunday, 20th June, 1948

[Received 15th January, 1949]

Report by the Director : R. Casey, F.G.S.

THIS meeting was organised for the purpose of studying the Albian succession in the neighbourhood of Folkestone. To some extent it combined the programmes of the 1934 [4]* and the 1938 [1] meetings, the former devoted principally to the classic Gault exposures at Copt Point and East Wear Bay, the latter to the Folkestone Beds of the Lower Greensand in their outcrop from Sandling (Hythe) to Folkestone.

A party of 25 or more assembled at Sandling Junction and was conducted to the large sand-pit just above the Station. This pit was described in 1939 [1, p. 368]: it has a depth of about 40 feet and affords an exposure of the upper half of the Folkestone Beds, which may be regarded as constituting a highly variable, thick, sandy base to the Gault. Before pointing out the special features of interest in the pit, the Director discoursed on the Folkestone Beds in general, mainly from the point of view of their palaeontological characters and zonal classification, though such questions as the mode of deposition of the beds and the possibility of an aeolian origin for parts of the formation in North Kent and Surrey were touched upon. It was emphasised that in the type area there was no question of the beds being anything but marine. On the whole they give the impression of having been accumulated rapidly in a shallow, current-swept sea, though the presence, locally, of beds rich in glauconite, lime and organic content, suggests deposition under more restricted conditions, while the occasional bands of phosphatic nodules with rolled fossils appear to indicate periods of actual submarine erosion or re-working of sediment. As evidence of the unstable conditions which preceded the deposition of the Gault, reference was made to the remarkable changes in lithology and thickness which the various zonal divisions of the Folkestone Beds undergo within the relatively small area traversed by the party. Unfortunately, it is not possible to identify these zones by characters which are obvious in the field, and the interpretation of each section has demanded a patient search for diagnostic fossils. In the course of this work the Folkestone Beds have proved to be a veritable treasure-house for the palaeontologist, and the eventual description of the fauna should add materially to our knowledge of the Lower Cretaceous System in this country.

Since the Association's visit in 1938 the working face at Sandling has receded considerably and the feather-edge of the Gault has now

* For list of References, see p. 225.

been reached at the western end of the pit. The "Red Bed," which 10 years ago was a rib of solid ferruginous rock, is reduced to a patchily indurated, impersistent seam; evidently it was only a large lenticle selectively limonitised. Interest was shown in the enormous stone "doggers" which are found in the top 12 feet or so of the section. They are composed of an intensely hard, almost crystalline, glauconitic sandy limestone and may be three feet thick and as much as six feet or more in length. They have to be dug out tediously by hand, and since there is no local market for the stone, they lie around the pit like megaliths.

Fossils collected by the party at Sandling included examples of the Hexactinellid sponge *Plocoscyphia*, which occurs in a silicified bank a few feet above the "Red Bed." The occurrence is noteworthy because at Folkestone, where spiculiferous sandstone is developed on a much larger scale, recognisable sponges are exceedingly rare.

The party proceeded to Folkestone by rail and walked through the town to East Cliff, where a picnic lunch was taken on the cliff-tops, overlooking the Channel and in sight of the French coast. After lunch the party descended the cliff at Baker's Gap to examine the Folkestone Beds and the Gault, which form the line of cliff extending from east of the Harbour to Copt Point. This magnificent natural exposure may be regarded as the type-section of the English Albian. The following table summarises the zonal classification now in use and shows its relationship to the minor stratigraphical divisions established mainly by F. G. H. Price [2] :—

	Zones	Beds	
Upper Albian	{ <i>dispar</i> <i>inflatum</i>	XIII IX-XII	Upper Gault
Middle Albian	{ <i>lautus</i> <i>dentatus</i> <i>mammillatum</i>	IV-VIII I-III 4	Lower Gault
Lower Albian	{ <i>tardefurcata</i> <i>nodosocostatum</i> (pars)	2-3 1	Folkestone Beds

Referring to the Folkestone Beds at East Cliff, the Director pointed out that the 60 feet of yellowish greensands with its bands of calcareous and glauconitic sandstone belonged mostly to the *tardefurcata* zone. Only the thin, nodular basement-bed at Folkestone can be assigned to the *nodosocostatum* zone, which makes up nearly the whole of the succession at Sandling, five or six miles to the west. In the course of explaining the zonal relationships of the underlying divisions of the Lower Greensand, the Director stated, however, that a revision of the ammonoidea of the Folkestone Beds and work along other lines led him to believe that the lower limit of the Albian lay within the Sandgate Beds. The evidence for this view will be published in due course.

Approaching Copt Point, members noted that the massive blocks of sandstone and grit which lay in profusion along the foot

of the cliff showed great variation in lithological detail, the blocks of glauconitic grit contrasting especially with those which had fallen from the seams of whitish, sinter-like "sponge-rock." These seams of "sponge-rock" are largely aggregates of sand-grains and sponge-spicules bound together by a calcareous matrix. Their weathered surfaces provide some of the best fossil-collecting in the Folkestone Beds: *Isocardia similis* J. de C. Sowerby, *Cucullaea glabra* Parkinson. *Trigonia* sp. nov., *Inoceramus* sp. nov., *Phyllobrissus artesianus* Hawkins, and a large undescribed species of *Holaster* are of fairly common occurrence.

The party made its way round the foot of Copt Point into East Wear Bay. Here the north-north-easterly dip brings the Gault down to the shore to form the floor over which the tide runs. The *mammillatum*-bed, at the junction of the Gault and Lower Greensand, comes down to sea-level a little to the east of Copt Point and at low water its outcrop may be followed for a hundred yards or more among the seaweed-covered reefs. From the concretionary masses of grit and phosphatic nodules which constitute the *mammillatum*-bed the party obtained a great number of fossils, the index-ammonite, *Douvilleiceras mammillatum* (Schlotheim), and its constant associate, *Beudanticeras ligatum* (Newton and Jukes-Browne), being readily forthcoming.

In East Wear Bay the various beds of the Gault, with their iridescent fossils—the delight of generations of collectors—were tolerably clear of sand. The Director paid tribute to the careful systematic work of previous investigators of the Folkestone Gault, particularly the classic account by F. G. H. Price [3] and the more recent researches of Dr. L. F. Spath, embodied in that authority's great monograph of the Gault Ammonoidea [5].

On the return journey from East Wear Bay, via the Warren, the slumped masses of Chloritic Marl and Lower Chalk engaged some desultory attention, and when a suitable vantage point above the Warren was reached, features of general interest such as the Chalk cliffs, the vestigial Lenham Beds, and the famous landslip area, were briefly discussed.

Tea was taken at the East Cliff Pavilion and the customary vote of thanks to the Director was moved by the President, Mr. E. E. S. Brown.

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THE SUPPOSED SILURIAN FORAMINIFERA FROM CARDIGANSHIRE

By ALAN WOOD

[Received 9th March, 1949]

SUMMARY—Material from the Silurian rocks of Cardiganshire, described by Blake and Keeping as containing Foraminifera, has been re-examined. The markings are considered to be inorganic.

IT has gradually become apparent, during the last decade or so, that records of calcareous Foraminifera in the early Palaeozoic rocks must be treated with the greatest reserve. In this the modern viewpoint is remarkably contrasted with that of earlier workers, who did not hesitate to consider specimens supposedly from Cambrian or Silurian beds identical with those from modern seas. Recently a fortunate chance has placed in my hands the original specimens of certain Silurian Foraminifera and, as will be shown, they do not appear to be of organic origin.

In the *Geological Magazine* for 1876 (p. 134) the Rev. J. F. Blake announced the discovery of "Dentalian Foraminifera" from beds considered to be of Caradoc age, about eight miles east of Aberystwyth. He stated that the shell had perished, but the walls between the chambers could be obscurely seen. "The most perfect of these hollow casts," he wrote, "could not be distinguished from that of *Dentalina communis*."

The specimen was presented to Walter Keeping, then Professor of Natural Science at the University College of Wales, Aberystwyth, and Keeping obtained further material which he described in the *Geological Magazine* for 1882 (p. 490). He showed that the specimens were of Lower Llandovery age. Figures were given of three types, *Dentalina*, *Textularia* and *Rotalia* (?). It was claimed that the original camerated structure could be clearly seen, the chambers still being hollow. The specimens were, he said, indistinguishable from common living species, and for this reason no new specific names were given.

The record has been noted by Dr. J. A. Cushman¹ and it is clear from his discussion of the early Foraminifera how rare are authentic specimens from beds of this age.

The original material is still preserved in the Geological Museum of the University College of Wales, Aberystwyth. It consists of four pieces of hard grey shale with the bedding accentuated by cleavage parallel to it, labelled in Keeping's handwriting "Cwm Symlog, N. of Goginan, 1878" (numbers 10176, 15960, 15961 and 19998) and one piece (number 15970) from which a label identical

¹ *Foraminifera*. 1947, p. 48. Harvard Univ. Press.

in size and shape has become detached. One of the specimens, of slightly coarser lithology, has added to the bottom of the label, clearly as an afterthought, "Pres'd J. F. Blake" and on this specimen the final 8 of 1878 has been obliterated, probably by the attempt to write a figure 5 on top. This specimen has on the reverse side obscure markings, which though they can hardly be claimed to be those of *Nereites Sedgwicki* (Blake 1876), are at least organic tracks.

This evidence has been given at length because it is important, in view of the categorical statements made that chambering and shape were identical with those of modern types, to be certain that the specimens are those described by Blake and Keeping.

Blake's specimen shows on one bedding plane a large number of minute elongated bodies, brown against the grey rock, in haphazard arrangement. When viewed with a hand-lens they appear needle-like and *Nodosarian*. The infilling material, which may or may not fill the cavity, is brown powdery iron oxide. In a few instances what appears to be chambering may be seen, in that a cavity incompletely filled is traversed from side to side at intervals by the iron oxide. A few flattened patches of roughly circular shape are also present on the bedding plane. Occasionally one can see one of the elongate bodies lying obliquely, when it is found to be not circular in cross section, as would be a *Dentalina* or a *Nodosaria*, but to be elongated also in a direction at right angles to the bedding, and hence of platy form. On looking at the fractured edges of the specimen, a large number of roughly circular brown patches may be observed whose diameter is the same as the length of the supposed *Dentalina communis*. The needle-like "*Dentalinae*" are clearly cross-sections of plates lying at right angles to the plane of bedding (and cleavage).

One of the specimens labelled by Keeping (15961) has on its label "No. 2 (Fig'd)" and within an ink-circle is what is presumed to be the original of Keeping's figure 15c. (Plate 8, Fig. A). This is a roughly circular brown spot, whose surface is rough, and of varying depth, the deepest part being in the middle. It is about 0.8 mm. in diameter, and shows an irregular indentation of the outline, originally interpreted as chambering. No trace reminiscent of organic structure is seen, other than this indentation, which appears to be entirely accidental, and there seems no doubt that this specimen too is of inorganic origin. Many of the elongated "*Dentalinae*" are present on the same surface. An irregular knottiness of the surface of the shale, reminiscent of spotted slate, is found to be due to the growth of clusters of minute crystals of pyrite. On the edges of the specimen a few broad plates can be seen, clearly the remains of the mineral whose cross sections gives the dentaline appearance on the bedding plane. There are also many extremely minute circular brown specks whose size is much

nearer that of cross sections of *Nodosaria* or *Dentalina*. When nine of these were carefully excavated with an extremely fine needle it was found that they did not continue into the rock, as they would if they were cross-sections of elongate foraminifera, but that they too are platy and flattened at right angles to the bedding.

A study of the other original specimens leads to similar conclusions. On one specimen (19998) I have carefully removed the infilling material from four of the elongated "foraminifera" and find that in one case the cavity is several times deeper than the cross-section, and in all cases the contact of rock with infilling is a smooth plane surface, showing no sign of having been moulded about a chambered test.

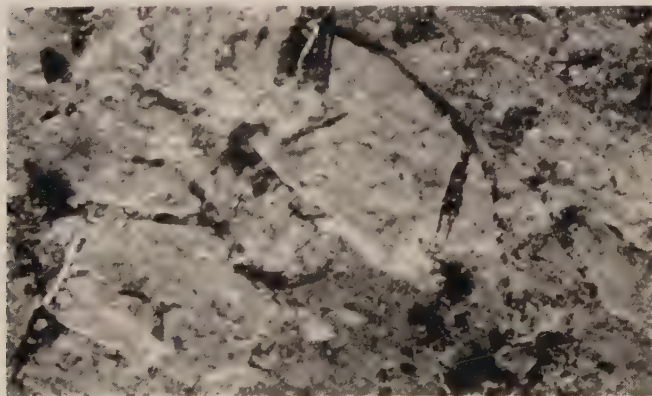
Lest it should be thought that a chambered structure was originally present and had been destroyed since the specimens were deposited in the museum, perhaps by careless handling, a search has been made for additional material from the type locality. This is found in abundance in the debris below the large reservoir dam, at Cwmsymlog (National Grid Reference 706837) and has been found *in situ* in a small quarry on the north side of the reservoir dam, being the first excavation to the south side of the track which runs along the water's edge in an easterly direction. Similar (loose) material can be found, showing the bodies in even greater profusion, to the south of the dam. (Plate 8, Fig B). It has been possible to excavate this material more freely than the original specimens, and I have not found in any instance the slightest vestige of chambered structure on removal of the infilling. Excavation of both sides of specimens freshly revealed by splitting the rock has confirmed their platy character. With the new material it has been possible to observe the stages of growth of these bodies, and it is particularly noticeable that they are very much slimmer in proportion to their length in the early stages than they are when fully grown. If they were to be considered as foraminifera a new type of growth plan would be required, in which the individuals grew not only in length but also uniformly in breadth.

Examples of these bodies have been submitted to the mineralogical department at the British Museum (N.H.) and the experts there concur in considering them to be of mineral origin. It is suggested that the mineral may possibly have been originally marcasite or mispickel.

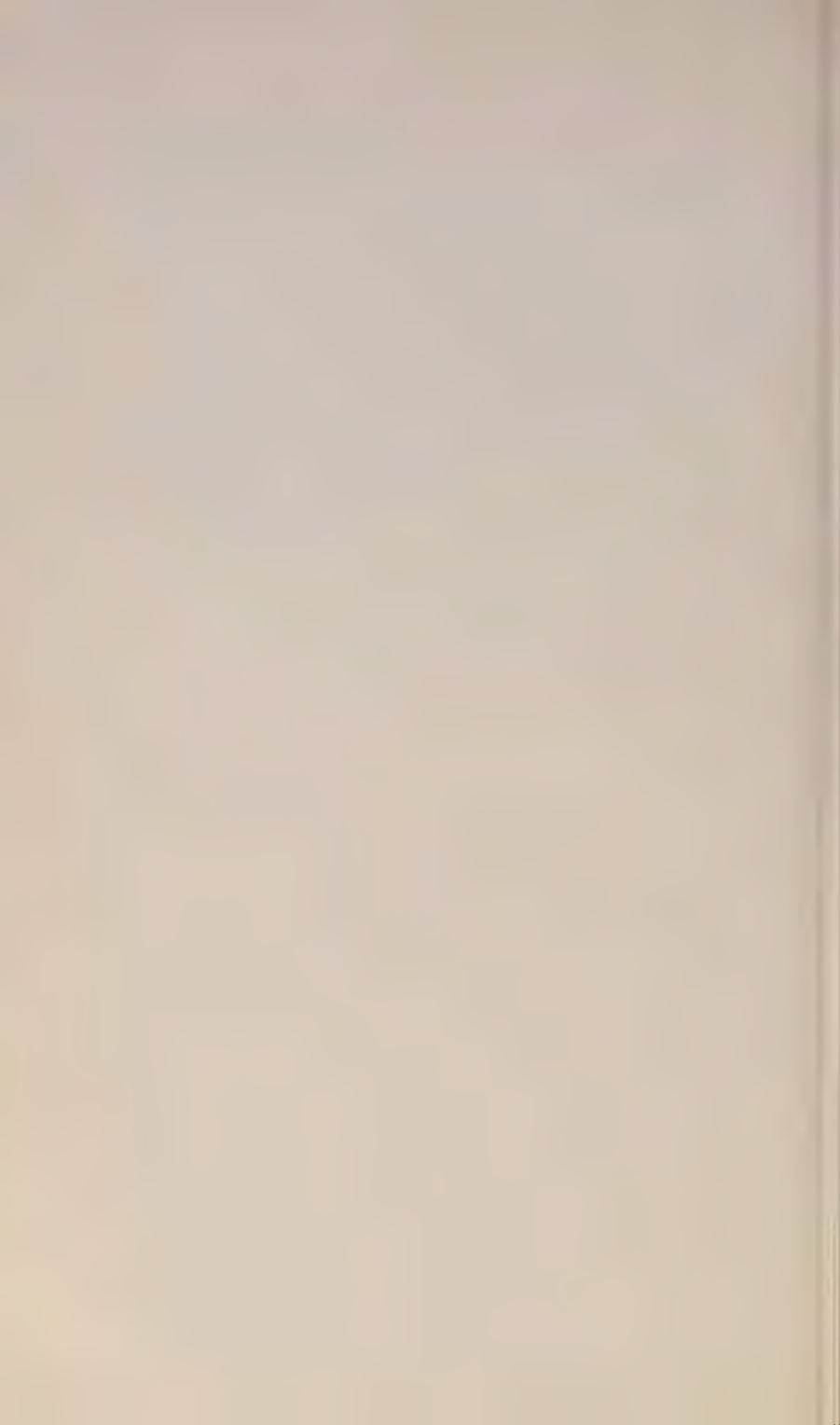
My thanks are due to Dr. Campbell Smith and Mr. Game for examining the specimens and confirming their inorganic character, and especially to Mr. J. Challinor who informed me of the survival of Keeping's original material.



A.—Specimen enclosed in ink circle by Keeping in 1878 and labelled “No. 2 (figd.).” Probable original of figure 15c of Keeping 1882, “*Rotalia*?” One of the supposed *Dentalinae* is visible in the lower right hand corner. U.C.W. collection 15961. Cwm Symlog, Near Goginan. X 23.



B.—Specimen to show the arrangement of “*Dentalina*” on the surface of the shale, and the parallel sided character of these impressions. A minute lichen fills the cavities on this weathered and slickensided surface. Cwm Symlog, near Goginan. U.C.W. collection 20005. X 23.



DEMONSTRATION AT BRITANNIC HOUSE, FINSBURY CIRCUS, E.C.2

27th November, 1948

Report by : P. Evans, M.A., F.G.S., and N. L. Falcon, M.A., F.G.S.

[Received 7th December, 1948]

ABOUT one hundred members accepted the invitation of the Directors of the Anglo-Iranian and Burmah Oil Companies to see something of the geological work of an oil company, and were shown over a varied collection of exhibits by Messrs. G. M. Lees, P. Evans, F. D. S. Richardson, N. L. Falcon and A. G. Davis.

The production of crude petroleum is an example of an industry depending for its raw material on the work of geologists and geophysicists, and the exhibits arranged by the Burmah Oil Co. in the entrance hall of Britannic House were designed to illustrate the main geological factors bearing on the accumulation of oil as well as to indicate the nature of the work which goes on in the geological department of an oil company. A number of diagrams referred to the formation and concentration of petroleum and drew attention to the principles underlying the work of a geologist engaged in prospecting for oil.

Geological maps on small and large scales were shown for areas in Burma, India and Pakistan, together with small-scale sections to illustrate regional geology and large-scale sections showing local structure. Several examples of maps constructed by stereoscopic examination of air photographs showed the usefulness of this modern method of assisting geological mapping, not only in open deserts but also in country covered by forest. Another aid to mapping is provided by sedimentary petrology which has proved particularly useful in Assam where the Tertiary rocks have remarkably few fossils, and some of the heavy mineral range tables were exhibited to indicate the basis of correlation.

Diagrams were shown to illustrate the principles of geophysical surveying and of some of the instruments used in the survey work. Examples of gravity maps were displayed and also a few records and results of seismic surveys. Considerable interest was shown by members of the party in the application of the resistivity method of electrical surveying which has been used with success in an alluvium-covered area in the Digboi oilfield. It was pointed out that no geological or geophysical method can tell in advance whether or not oil is actually present in an area ; the only way of finding out is to drill a test well. The test well is located after a careful scrutiny of all relevant geological and geophysical evidence but even so the great majority of prospecting wells fail to

find oil in commercial quantities. Diagrams were displayed to show some of the reasons for failure.

The exploration geologist is concerned with the search for new oilfields and the development geologist with obtaining the best out of these fields when they are found. In the course of his work he depicts the structure by underground contour maps of important horizons and by drawing cross-sections. These necessitate an exact correlation from well to well, which is a difficulty in the rapidly varying shallow-water deposits characteristic of many Tertiary oilfields, but the introduction of electric logging has given an accurate method of recording lithological changes in beds drilled through. Some examples of electric logs were shown, as well as a number of maps and sections. The concluding items in the exhibition were a diorama showing the general appearance of the Yenangyaung field, a number of photographs in the Burma oilfields and at Digboi, and an illustration of the old hand-dug well of some of the Burma fields.

The Anglo-Iranian Oil Company's demonstration consisted of a palaeontological exhibit, and a series of maps, sections and diagrams, illustrated by air photographs, designed to bring out the salient features of the geology of south-west Iran. The mountain belt of south Iran marks the site of a north-west—south-east orientated geosyncline in which marine sedimentation was almost continuous from Permian until Miocene times, the only important interruptions to this placid deposition occurring in marginal areas in the Cretaceous. At the beginning of Upper Cretaceous times orogenesis, locally of great violence, caused facies changes and unconformities in what is now the north-east of the mountain belt, and intrusions of early Cambrian salt were initiated in the southern part of the geosyncline. The main folding of the mountain belt, now strikingly laid bare by erosion, is of post-Miocene age. The higher mountains, exposing rocks down to early Cambrian age, provide a natural demonstration of geological structures which can hardly be surpassed, as the many air photographs on view demonstrated.

The oilfields are situated in the foothill region, where the Asmari Limestone reservoir rock of Oligocene—Middle Miocene age is sealed by the succeeding Lower Fars evaporite series, but is not too deeply buried to be accessible to the drill. Depths of producing wells are usually between 3000 and 8000 feet.

The complex disharmonic folding caused by the plasticity of the overlying Lower Fars formation, which contains considerable amounts of salt, makes it difficult to forecast the pattern of the sub-surface limestone anticlines from a study of surface geology alone, and geophysical methods must also be employed. This characteristic feature of Iranian oil geology was illustrated by a series of maps of the known oilfields, with tracings superimposed

showing the contours of the underlying Asmari Limestone, and also by a series of cross-sections based on well evidence. On a number of sections arc-time graphs, constructed from seismic data, showed how the concealed Asmari Limestone anticlines can be located by seismic means.

In south Iran the great size and thickness of the limestone reservoirs, and other favourable factors, provide almost ideal conditions for oil accumulation, storage and production. Individual wells producing one million gallons a day of crude oil are not unusual, and it is unnecessary to drill with the close spacing of bore holes usually required in sand fields (as, for example, in Burma and in the small English field at Eakring).

A number of exhibits showed the value of vertical air photography as an aid to geological work under semi-desert conditions. Excellent exposures, and well-defined structures, make it possible to use photographs in various ways for reconnaissance and detailed mapping.

Three exhibits were devoted to the intrusions of Lower Cambrian salt, already referred to, which have formed numerous well-exposed salt plugs. Although, unlike many of the concealed salt plugs of other lands, they have no direct bearing on oil accumulation, they have considerable scientific interest. Many of them have punctured a sedimentary column over 20,000 feet in thickness to reach the surface.

The importance of palaeogeographical studies in oil geology was brought out by two diagrams illustrating recent stratigraphical work. Although the location of oil accumulations in being is largely dependent on structure, a comprehensive knowledge of facies distribution in reservoir rocks and presumed source rocks is necessary before the problems of oil formation and migration can be investigated.

The complicated nature of the tectonics on the north-eastern side of the mountain belt (that is the south-west edge of the Iranian plateau of the geographers) was demonstrated by a map and sections across a tectonic window, considered to prove that great overthrusting to the south-west occurred in early Upper Cretaceous times in some areas. The Tertiary movements also caused considerable thrusting to the south-west along this general line, but no evidence is yet available to prove that the thrusts attained "nappe" dimensions, although this is quite probable.

The palaeontological exhibit showed a fairly representative collection of macro-fossils and larger foraminifera, mainly from the upper part of the south Iranian succession. (Additional material, including that from the Palaeozoic, is available at the Natural History Museum and the Oxford University Museum.)

A final item was a collection of surveying instruments used by

field geologists, who rarely, in oilfield work, have the advantage of a previously prepared accurate topographical map to assist them.

After members had had an opportunity of visiting both groups of exhibits, tea was served in the Britannic House canteen. The President thanked the Directors of the Anglo-Iranian and Burmah Oil Companies for their hospitality, and the members of the geological staffs of the two companies for their work in arranging the exhibition and for their comments on the maps, diagrams, photographs and other exhibits.

DEMONSTRATION AT HUNTING AEROSURVEYS LTD.

11th December, 1948

Report by : J. F. Kirkaldy

[Received 7th January, 1949]

ABOUT 40 members assembled for a morning visit to the laboratories of Hunting Aerosurveys Ltd. at Boreham Wood, Herts. The programme consisted of a comprehensive tour of the laboratories and members were shown all stages in the preparation from aerial photographs of detailed maps and plans, some on as large a scale as 1 : 480. Particular attention was given to the numerous vertical and oblique photographs of geological features, the stereo-plotting machines and the modelling shop. The stereo-plotters enable accurate contours to be drawn, provided there is the necessary minimum of ground control, with a vertical interval of as little as 10 or even five feet. In the modelling shop it was shown that by examining aerophotographs stereoscopically, attention could be paid to the many significant topographical features that are missed by the wide contour interval of the existing Ordnance Survey maps. For example, a model on the scale of 1 : 16,000 of the Balmoral Estates could be used with advantage, in any university department, for teaching the detailed topography of glaciated country.

The meeting concluded with the President (Mr. E. E. S. Brown) voicing the thanks of those present to the Technical Manager (Mr. T. D. Weatherhead, O.B.E., M.A.) and his staff for such an interesting and instructive tour.

DEMONSTRATION AT KEW OBSERVATORY

Saturday, 15th January, 1949

Report by : J. F. Kirkaldy

[Received 17th January, 1949]

APARTY of 30 members were conducted round the Observatory by the Superintendent, Dr. Robinson, and by Dr. Lee. Dr. Robinson demonstrated the wide range of meteorological instruments used for routine observations and for specialised research. Dr. Lee gave an interesting account of the two types of seismographs in use and exhibited a number of seismograms of earthquakes felt in the last few months. The proceedings closed with a hearty vote of thanks from the President.

THE LOWER CORALLIAN ROCKS OF THE YORKSHIRE COAST AND HACKNESS HILLS

By VERNON WILSON, Ph.D., M.Sc., D.I.C.

[Received 25th November, 1948]

[Read 7th January, 1949]

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SUMMARY.—Sections in the Lower Corallian rocks on the coast at Filey and Scarborough and in the Hackness Hills are described. Evidences of repeated intraformational erosion in the Hambleton Oolite beds at Filey are recognised and the structures known as “fucoids” occurring at the bases of many of the beds are thought to be weathered-out infillings of sun-cracks. The detrital quartz grains diminish in profusion and size towards the north-west, implying derivation from the east or south-east. The palaeoecology of the Hambleton Oolite Coral-Sponge reef in the Hackness Hills is discussed in relation to the faunas of the equivalent beds at Scarborough and Filey. New species of *Holcospongia* and *Peronidella* are also described.

INTRODUCTION

THROUGHOUT the main northern outcrop of the Corallian Rocks across North-East Yorkshire there is a gradual attenuation from west to east. In the coastal area this thinning is particularly marked in the Lower Corallian Beds (Lower Calcareous Grit, Hambleton Oolites and Middle Calcareous Grit) towards the south-east from the Hackness Hills to Filey, and it is accompanied by considerable variations in the lithology and in the character and distribution of the fossils.

In the following pages these lithological and faunal variations are discussed in relation to the probable nature of the sea floor and the conditions of sedimentation under which the deposits accumulated. There is evidence to show that at the end of Lower Calcareous Grit times and during the succeeding Hambleton Oolite and Middle Calcareous Grit episodes the sea was remarkably

shallow in this area and it is suggested that there may have been low lying land at no great distance to the south-east.

The Corallian rocks in this area aroused the interest of William Smith during his six years residence at Hackness, and in describing them in 1829 [36*] he gave a remarkably accurate account of the local succession in that district, recognising the peculiar and prominent part played by the calcareous sponges in the early coral-sponge reef of the Hambleton Oolite episode. His succession is as follows :—

Coralline	{	Limestone
Oolite		Spongite Coral Bed
		Grey or Wall stone
Calcareous	{	Reddish yellow sand, corresponding with the indurated sand exposed on the north side of Scarborough Castle Hill
		Cherty bed of stone which forms the plains of the moors and the high well-defined edge of the Tabular Hills
		Freestone beds below this
Oxford Clay		

In describing the Coral Bed he says, it “is a more earthy bed reposing on the greystone, only about 6 feet containing lumps of coral and small spongites, which distinguish it from the coral over the limestone”; from these last four words it is evident that Smith realised this coral rag to be quite distinct from, and earlier than, the later coral rag of the Higher Osmington Oolites.

John Phillips [30] has also detailed bed by bed the various sections between Filey and Scarborough, recognised the characteristic fossils and described and figured many new species.

In spite of the care with which Blake and Hudleston recorded sections and other evidence [12], it is apparent in so far as this area is concerned that they were not entirely satisfied with their interpretations. For example, they state [12], p. 385 “the section at Filey still remains somewhat problematical,” and again a few lines farther on, in referring to the section at Scarborough Castle Hill, “this section is more imperfect than that at Filey”; still farther on (p. 386) they state, “The Middle Calcareous Grit is rather irregular and uncertain. It seems to break out in Filey Brigg.”

The official geological survey was carried out principally by Barrow and Fox-Strangways, the accounts of these rocks by the latter were largely based on the findings of Blake and Hudleston and contain little new information.

During the present investigation all available sections have been re-examined and recorded in detail, new evidence brought forward and new collections of fossils made, and in the ensuing pages an attempt is made to resolve the difficulties which were encountered by Blake and Hudleston.

* For list of References see p. 268.

Here, I should like to express my thanks to Dr. W. J. Arkell, F.R.S., for his ever willing help and encouragement in these problems in Yorkshire ; he has read this manuscript and offered many valuable comments and useful suggestions which it is a pleasure to acknowledge.

GENERAL SUCCESSION, LITHOLOGY AND FAUNA

The general sequence in the area under discussion comprises the three lower sub-divisions of the Corallian and is summarised in the following table :—

Zones	Filey	Scarborough	Hackness District	
<i>Perisphinctes plicatilis</i>	Thick brown wedge-bedded sandstones with lenses of detrital lime-stone, 15ft.	Absent	Unfossiliferous ferruginous sandy lime-stones with fine shell debris and scattered ooliths, 20ft.	MIDDLE CALCAREOUS GRIT
<i>Cardioceras cordatum</i> ss.	Calcareous gritstones with sun-cracked layers and indurated beds, 28ft.	Impure oolitic limestones, 26ft.	Oolite, 30ft.	HAMBLETON OOLITE SERIES
<i>Cardioceras costicardia</i>		Gritstones and detrital lime-stones, 28ft.	Coral-Sponge Rag, 11ft. Brown sandy detrital lime-stones, 25ft.	
<i>Cardioceras bukowskii</i>	" Ball Beds," 10 to 18ft.			LOWER CALCAREOUS GRIT
<i>Cardioceras praecordatum</i>	Hard cherty band, 3 to 7ft. Massive buff gritstones, 50 to 115ft.			

Lithologically these rocks show every kind of deposit from fine arenaceous types to pure oolites with a phase of reef growth in the lower part of the Hambleton oolites in the Hackness neighbourhood.

The Lower Calcareous Grit.—The Lower Calcareous Grit consists mainly of fine-grained calcareous gritstones and is sub-divided as follows :—

3. The " Ball Beds." (*bukowskii* zone) 10–18 feet thick. Incoherent soft ferruginous sandstones containing hard limestone doggers varying in size from a few inches to 3 or 4 feet in diameter occurring sporadically or in lines and layers.
2. Hard blue-grey cherty gritstone band, 3–7 feet thick.
1. The main mass of the calcareous grit (*praecordatum* zone), 40–115 feet thick, comprising thick beds of hard buff

gritstones, often blue centred, with no trace of current bedding. These beds pass down gradually without any sharp line of demarcation into the underlying Oxford Clay.

The whole series is lithologically constant along the coast and throughout the Hackness Hills. The limestone doggers in the "Ball Beds" are fairly fossiliferous and at Scarborough and Filey where they are well exposed they have yielded spicules of *Rhaxella perforata*, *Chlamys fibrosa*, *Exogyra nana*, *Astarte ovata*, *Meleagrinnella ovalis*, *Trigonia triquetra*, *Rhynchonelloidea thurmanni* and

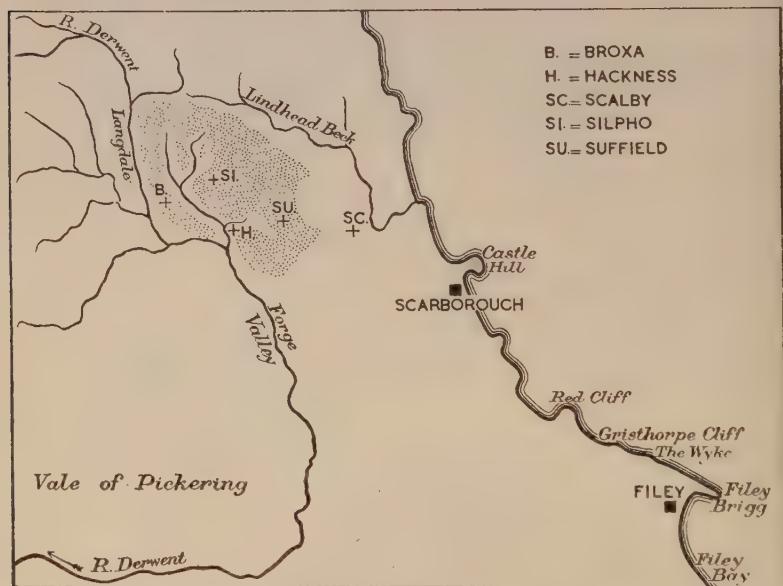


FIG. 40.—SKETCH-MAP OF THE YORKSHIRE COAST between Filey and Scarborough and the Hackness Hills (shaded) area. (Scale about 4 miles to 1 inch.)

Nucleolites scutatus. In the main mass of the grit, below the "Ball Beds," well exposed at Scarborough Castle Hill, Cayton Bay and in the Gristhorpe Cliffs spicules of *Rhaxella perforata* are very abundant, and *Rhynchonelloidea thurmanni*, *Chlamys fibrosa*, *Astarte ovata*, *Exogyra nana*, *Trigonia triquetra*, *Meleagrinnella ovalis*, *Gryphaea dilatata*, *Lima laeviuscula*, *Gervillia aviculoides*, *Modiola bipartitus*, *Isognomon quadrata*, *Pinna lanceolata*, *Collyrites bicordatus*, *Pachyteuthis abbreviatus* and *Serpulae* are common.

The Hambleton Oolites.—Throughout their main outcrop in the Tabular Hills these rocks are mainly oolites but in this area they vary in lithology, thickness and fauna. The change from the sandy

"Ball Beds" with their limestone doggers at the top of the Lower Calcareous Grit to the succeeding impure limestones is gradual. These calcareous gritstones and impure limestones are 28 feet thick at Filey and the uneven indurated character of the lower beds and occasionally at higher levels indicates intra-formational erosion. The following ammonites have been recorded from these beds :— *Cardioceras* (*Subvertebriceras*) *costellatum* and *C. (Cardioceras) costicardia*. Farther north, at Scarborough Castle Hill, the beds have thickened to 54 feet, of which the upper 26 feet are impure oolitic limestones while the lower beds are made up of variable gritstones and hard detrital limestones containing *Perisphinctes bernensis*.

In the Hackness district five miles west-north-west of Scarborough the oolites in the upper part have increased to 30 feet, probably their full development hereabouts ; below these is a well developed coral-sponge reef whose maximum thickness is 11 feet, which is underlain by 25 feet of brown sandy detrital limestones. The occurrence of a reef deposit at this low horizon in the Hackness Hills is unique in the British Corallian sequence.

While the Lower Calcareous Grit yields a fauna somewhat poor in species the sub-divisions of this period contain a fair abundance of characteristic forms. The majority of the species present in the underlying gritstones persist into the lower beds of the Hambleton Oolites, but new forms, many of which are small, appear and to some extent herald the very fossiliferous Osmington Oolites of later date. It was, however, in the Hackness reef where life was most varied, prolific and localised. Lithologically this reef consists of an intimate mixture of large and small lenses of compound coral with large numbers of calcareous sponges, terebratulids, reef detritus and fine mud, together with an abundant fauna of molluscs and other fossils different in many respects from those associated with later episodes of coral growth. Most of the corals belong to species which take part in the widespread developments of reefs at higher Corallian horizons in England. This community of corals, sponges and terebratulids is an interesting faunal association not found elsewhere in this country, and here also is the earliest occurrence of a small molluscan fauna, comprising *Lima zonata*, *Lithophaga inclusa*, *Chlamys nattheimensis*, *Lopha gregarea* and *Xysterella muricata*, confined to the reef habitat.

In the coastal area, particularly at Filey, in addition to the ammonites mentioned above, the gritty limestones also contain an abundant fauna in which shallow water forms predominate. Besides many of the calcareous sponges and terebratulids characteristic of the Hackness reef there are the remains of the crinoids *Milleri-crinus echinatus* and *Pentacrinus*, echinoderms are represented by *Pygurus pentagonalis*, *Pseudodiadema versipora*, *Acrosalenia decorata*, *Paracidaris florigemma* and plates of the starfish *Astropecten*,

together with hosts of the ubiquitous little *Exogyra nana*, *Lophagregarea*, *Gryphaea dilatata*, *Gervillia aviculoides* and countless entangled knots of *Serpula intestinalis* and *S. tricarinata*, all indicative of very shallow water.

The Middle Calcareous Grit.—In the Hackness Hills the Hambleton Oolite is succeeded by 20 feet of unfossiliferous ferruginous sandy limestones containing a high proportion of comminuted shell debris and scattered ooliths. These beds are rarely exposed at the present time but they give rise to a rich reddish brown loamy soil carrying rubble of the underlying rock ; this is very noticeable around the village of Silpho.

On the coast beds of this age are only present at Filey, where they occur as thick brown wedge-bedded sandstones amounting to 15 feet ; they contain thin seams and lenses of detrital shelly oolitic limestone which tend to be more common in the upper part of the series. Fossils are not very common in these beds except for such persistent forms as *Gervillia aviculoides*, *Isognomon quadrata*, *Chlamys fibrosa*, *Gryphaea dilatata* and *Meleagrinella ovalis*. The thin limestones yield faunas which include such common forms as *Trigonia huddlestoni*, *Lima laeviuscula* and *Astarte ovata*.

In order to appraise the full significance of the variations in thickness, lithology and faunas of the Corallian rocks in this area it is now necessary to examine in detail all the available sections where they are displayed from Filey Bay northward to Scarborough Castle Hill and in the nearby Hackness Hills to the north-west (Fig. 40).

STRATIGRAPHICAL DETAILS

(a) The Coast between Filey and Scarborough

The wide, smooth, concave outline of Filey Bay is carved out of the Kimmeridge Clay and its unstable covering of 125 feet of Boulder Clay cliffs ; on its north side it terminates abruptly against the straight southern flank of a long promontory of hard Corallian rocks overlain for about half its length by 100 feet of boulder clay. The landward drift-covered part of this peninsula is known as Filey Carr Naze, and the sea-swept part of it to the east is known as the Brigg. The Corallian beds dip southward towards the bay at 8°, and within a few yards of the low-tide mark on the south side they are truncated by a strong fault which brings down the Kimmeridge Clay into the floor of the bay (Fig. 41).

The foundations of the Brigg below the sea are formed by the Lower Calcareous Grit while the Hambleton Oolite beds and Middle Calcareous Grit form the exposed craggy part above the water ; the latter also forms the greater part of the south side of the Carr Naze. Thin basal beds of the Osmington Oolite, much broken and churned up in Glacial times, form a thin outcrop beneath the steep boulder clay cliffs all round the Carr Naze. Of all the beds

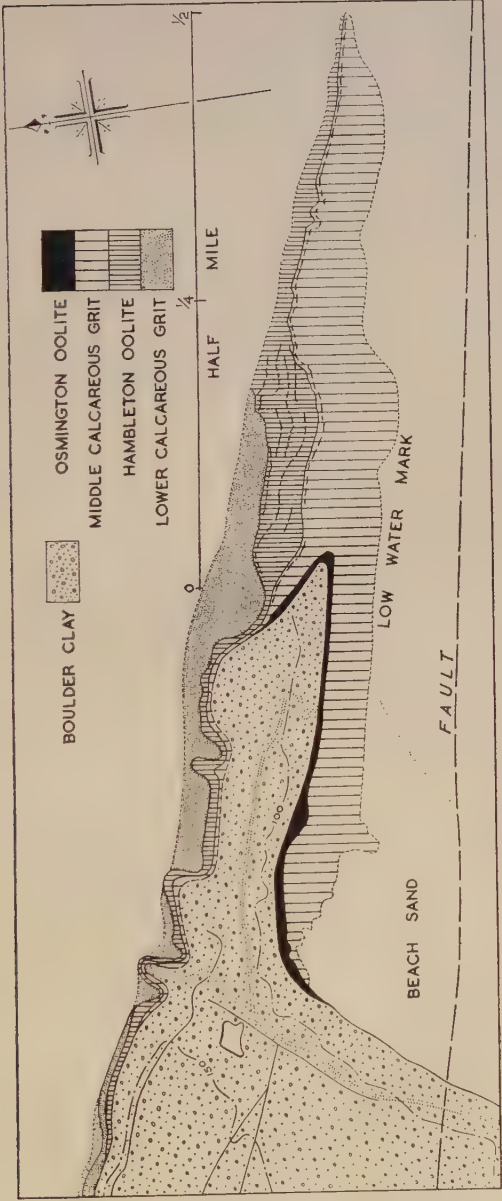


FIG. 41.—SKETCH-MAP OF THE GEOLOGY OF FILEY CARR NAZE AND BRIGG.

displayed on the north side of the Carr Naze the "Ball Beds" at the top of the Lower Calcareous Grit offer the least resistance to erosion by the sea, and as the limestone doggers are loosened and freed from their matrix their movement by the sea further assists erosion. As a result of this action the overlying beds have been undermined in four places and have consequently collapsed and given rise to four large open marine caves or "doodles." It is on this north side of the Carr Naze that the whole sequence is most completely exposed and accessible for bed-by-bed examination. The following details and measurements have been recorded at the entrance to the first "doodle" (Plate 9).

SECTION ON THE NORTH SIDE OF THE CARR NAZE, FILEY OSMINGTON OOLITE SERIES

	ft.	ins.
34. Hard broken, detrital oolitic limestones covered by boulder clay. Seen to the best advantage on the south side of the Carr Naze ..	14	0
<i>Pleuromya uniformis</i> , <i>Lima rigida</i> , <i>Chlamys splendens</i> , and <i>Nucleolites scutatus</i> .		
33. Loose, nodular brash	1	0
<i>Ostrea quadrangularis</i> , <i>Chlamys splendens</i> , <i>Nucleolites scutatus</i> and <i>Holcetypus depressa</i>		
32. White detrital shelly limestone	2	3
<i>Gryphaea dilatata</i> and <i>Trigonia</i> sp.		

MIDDLE CALCAREOUS GRIT

31. Thinly bedded, soft sandstone with nodules of shelly material in the upper part	2ft. 6ins. to	2	9
30. White detrital nodular limestone, shelly and oolitic in the upper part; this bed is packed with serpulid tubes		1	6
<i>Trigonia densicostata</i>	<i>Lopha genuflecta</i>		
<i>Gervillia aviculoides</i>	<i>Astarte ovata</i>		
<i>Meleagrinella ovalis</i>	<i>Pseudomelania heddingtonensis</i>		
<i>Ostrea quadrangularis</i>	<i>Xysterella muricata</i>		
<i>Ctenostreon proboscideum</i>	<i>Nucleolites scutatus</i>		
<i>Lima laeviscula</i>	<i>Serpula intestinalis</i>		
<i>Lima rigida</i>			
29. Thinly bedded brown fissile sandstone with "fucoids" in the lower part; the upper 4 inches consists of fine shell debris		2	0
<i>Astarte ovata</i>	<i>Gryphaea dilatata</i>		
<i>Goniomya literata</i>	<i>Pleurotomaria munsteri</i>		
<i>Pleuromya uniformis</i>			
28. Thin band of white porous grit	6 ins. to		9
<i>Trigonia densicostata</i>	<i>Lima rigida</i>		
<i>Gervillia aviculoides</i>	<i>Xysterella muricata</i>		
<i>Pleuromya uniformis</i>	and a fragment of a cordate ammonite		
<i>Gryphaea dilatata</i>			
<i>Chlamys splendens</i>			
27. Thick bed of brown sandstone		2	3
<i>Goniomya literata</i>	<i>Lucina</i> sp.		
<i>Pinna lanceolata</i>			
26. Thick bed of brown sandstone, the upper 9 inches to 1 foot tending to be a shelly limestone, from which the following fossils are recorded	4 ft. to	5	0
<i>Pholadomya aequalis</i>	<i>Lima rigida</i>		
<i>Gervillia aviculoides</i>	<i>Astarte ovata</i>		
<i>Meleagrinella ovalis</i>	<i>Xysterella muricata</i>		

*Trigonia densicostata**Holcotypus depressa**Gryphaea dilatata**Serpula intestinalis**Pleuromya uniformis*

25. Peculiar false-bedded buff sandstone with lines of small masses of coarser grit 2 0

HAMBLETON OOLITE SERIES

24. Hard buff grit with nodules containing spicules of *Rhaxella perforata*. *Gryphaea dilatata* 1 9
23. Hard sandstone full of "fucoids," and an occasional dogger containing spicules of *Rhaxella perforata* 9 ins. to 1 0
- Lopha gregarea* *Gryphaea dilatata*
- Goniomya literata* *Rhaxella perforata*
22. Brittle gritty nodular limestone with scattered ooliths 7 ins. to 9
- Lopha gregarea* *Lima rigida*
- Astarte ovata* *Pseudomelania heddingtonensis*
21. Thick brown sandstone with dark fucoid-like masses 1 9
- Pinna lanceolata* *Chlamys splendens*
20. Hard cherty grey gritstone, composed of *Rhaxella* spicules 8 ins. to 1 0
19. Brown, limestone-centred sandstone 1 ft. 3 ins. to 2 0
- Meleagrinella ovalis* *Gervillia aviculoides*
- Trigonia densicostata* *Lima rigida*
18. Grey limestone band 6 ins. to 10
- Pleuromya uniformis* *Pholadomya aequalis*
17. Brown sandstone, largely greystone centred; sandy in upper and lower parts with fucoids developed 1 ft. 1 in. to 1 3
- Gervillia aviculoides* *Nucleolites scutatus*
16. Thin, hard-centred sandstone with *Rhaxella* spicules 6 ins. to 10
15. Thin sandstone with dark fucoid-like nodules 9 ins. to 1 0
14. Hard, blue, gritty limestone, with coarse and fine shelly material in the upper part 2 0
- Lopha? genuflecta* *Gryphaea dilatata*
- Astarte ovata* *Rhynchonelloidea thurmanni*
- Meleagrinella ovalis*
13. Grey-white, gritty limestone, with fucoids in the lower part; much shell debris towards the top 2 ft. to 2 3
- Rhynchonelloidea thurmanni*
12. Hard, blue gritty limestone, the lower 6 inches of which is a sandstone with fucoids 2 ft. 3 ins. to 2 6
- Camptonectes lens* *Lima rigida*
- Gervillia aviculoides* *Rhynchonelloidea thurmanni*
11. Thick brown sandstone with uneven top and base. In places this bed tends to split into an upper gritty limestone with *Rhaxella* spicules and a lower sandstone (6 ins.) with fucoids 2 ft. 3 ins. to 2 6
- Trigonia densicostata* *Lopha gregarea*
- Gervillia aviculoides* *Xysterella muricata*
- Gryphaea dilatata* *Rhynchonelloidea thurmanni*
10. Thick bed of blue gritty limestone, sandy and fucoidal at the top and base with *Rhaxella* spicules in the fucoids 2 ft. 3 ins. to 2 9
- Pleuromya uniformis* *Lopha? genuflecta*
- Trigonia densicostata* *Gryphaea dilatata*
- Gervillia aviculoides* *Rhynchonelloidea thurmanni*
9. Hard gritty blue limestone with sandy base and uneven sandy top which tends to merge into the base of the bed above 1 0
- Holcospongia floriceps* *"Terebratula" fileyensis*
- Corynella chadwicki* *"Terebratula" sp.*
- Bastinia aspera* *Paracidaris florigemma*
- Millericrinus echinatus* (Young forms)
- Pentacrinus sp.* *Acrosalenia decorata*
- Rhynchonelloidea thurmanni* *Holcotypus sp.*

8. Hard sandy bed, light coloured and nodular in the upper part ; a blue gritty limestone with *Rhaxella* spicules in the lower part 1 ft. 6 ins. to 1 9
Gervillia aviculoides *Rhynchonelloidea thurmanni*
Lopha gregarea "*Terebratula*" *fileyensis*
Millericrinus echinatus "*Terebratula*" sp.
Pseudodiadema versipora *Holcospongia floriceps*
Nucleolites scutatus *Holcospongia* sp.
and fragments of cordate ammonites
7. Soft grey-brown shelly dirt band 6
Gervillia aviculoides *Nucleolites scutatus*
Astarte ovata *Holcospongia floriceps*
Rhynchonelloidea thurmanni
6. Hard grey, gritty limestone with irregular top and base ; shell debris and detritus in the lower part 1 3
Cardioceras costicardia *Acrosalenia decorata*
Lopha gregarea *Nucleolites scutatus*
Lopha ? genuflecta *Millericrinus echinatus*
Gervillia aviculoides *Holcospongia floriceps*
Rhynchonelloidea thurmanni *Rhaxella perforata* (spicules)
"*Terebratula*" *fileyensis*
5. Variable, hard, grey-brown current bedded sandy dirt bed, occupying the space between the irregular top of the bed below and the irregular base of the bed above 1 ft. to 1 3
Limatula elliptica *Rhynchonelloidea thurmanni*
Ctenostreon proboscideum *Serpula tricarinata*
Gryphaea dilatata and fragments of cordate
Lopha ? genuflecta ammonites
4. Grey sandy limestone, irregular top and base 8
3. Variable consolidated detrital dirt band 4
2. Grey gritty bed with irregular top and base 1 0
1. Grey gritty bed with irregular top and base 1 0

Fossils from beds 1, 2, 3 and 4 include :—

<i>Cardioceras costicardia</i>	<i>Rhynchonelloidea thurmanni</i>
<i>Gryphaea dilatata</i>	<i>Pseudomelania heddingtonensis</i>
<i>Lopha gregarea</i>	<i>Littorina muricata</i>
<i>Lopha genuflecta</i>	<i>Littorina muricata</i> var. <i>muricatula</i>
<i>Chlamys splendens</i>	<i>Nucleolites scutatus</i>
<i>Gervillia aviculoides</i>	<i>Pseudodiadema versipora</i>
<i>Camptonectes lens</i>	<i>Acrosalenia decorata</i>
<i>Trigonia densicostata</i>	Plates of <i>Astropecten</i>
<i>Astarte extensa</i>	and <i>Serpula intestinalis</i>

Chlamys fibrosa, *Exogyra nana* and one or more species of *Serpula* occur in every bed in the above section.

LOWER CALCAREOUS GRIT

- C. The "Ball Beds." Soft brown sandstone with occasional large limestone doggers. *Exogyra nana*, *Serpulae* and nests of *Holcospongia floriceps* are common 2 0
Soft sandstone with a 1-foot band of rounded limestone doggers 3 feet from the top of the bed 10 0
Soft sandstone with sporadic limestone doggers throughout the bed and a layer of them at the base 3 3
The above beds have yielded the following fossils :—
Chlamys fibrosa *Trigonia triquetra*
Lima rigida *Rhynchonelloidea thurmanni*
Lopha solitaria *Collyrites bicordatus*
Pinna lanceolata *Serpulae*



SECTION ON NORTH SIDE OF FILEY CARR NAZE.

B. Hard grey cherty bed largely composed of the spicules of <i>Rhazella perforata</i>		3	0
<i>Exogyra nana</i>	<i>Gryphaea dilatata</i>		
<i>Chlamys fibrosa</i>	<i>Serpulae</i>		
(Hard brown sandstone with <i>Rhazella</i> spicules		3	0
(Three irregular beds of blue-centred gritstone		4	10
(Hard irregular bed of pale greystone		1	3
A. Hard brown gritstone with an occasional limestone dogger		10	0
(Hard light blue limestone bed		3	0
Brown gritstones, seen down to low tide mark to		12	0
Fossils from the above beds A include:—			
<i>Homomya vezelayi</i>	<i>Placunopsis radiata</i>		
<i>Modiola bipartus</i>	<i>Trigonia triquetra</i>		
<i>Mytilus unguilatus</i>	<i>Rhynchonelloidea thurmanni</i>		
<i>Chlamys fibrosa</i>	<i>Hibolites hastatus</i>		
<i>Gryphaea dilatata</i>	and <i>Serpulae</i>		
<i>Lucina lirata</i>			

In the above section Beds 1 to 24 inclusive represent the attenuated Hambleton Oolite Series at this locality. They were regarded as being of this age by Hudleston [24] and were included in the "Lower

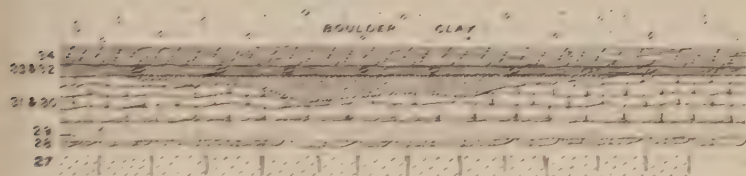


FIG. 42.—DIAGRAM SHOWING THE WASHOUT IN THE TOP OF THE MIDDLE CALCAREOUS GRIT ON THE SOUTH SIDE OF FILEY CARR NAZE.

Calcareous Series" of Blake and Hudleston [12, pp. 318-19]. Fox-Strangways [19 pp. 315-16], however, regarded all the beds between the Lower Calcareous Grit and the Middle Calcareous Grit (i.e., the Filey Brigg Grit) as belonging to the "Passage Beds" which the Survey [19] recognised as a separate sub-division between the Lower Calcareous Grit and their "Lower Limestone" sub-division or Hambleton Oolites; and he maintained that beds of the latter sub-division were unrepresented at Filey. On the faunal evidence these beds are of Hambleton Oolite age, and the Survey's "Passage Beds" are no longer justifiable as a sub-division of the Yorkshire Corallian sequence.

Of the beds above the Hambleton Oolite, beds 26 to 34 are exposed along the south side of the Carr Naze and dip southward beneath the sea at about 8°. The path leading along the foot of the cliff to the Brigg passes over Bed 28, and about 230 yards west of the kiosk at the eastern end of the boulder clay cliffs there occurs a remarkable washout in the top of the Middle Calcareous Grit (Bed 31). It is close to the steps leading up the cliff face at this point and is some 36 feet long and 2 feet deep (Fig. 42).

This washout shows current bedding on a small scale and it is composed of rough mis-shaped ooliths and comminuted shelly material with eroded micromorphic gastropods. The comminution points to surf action and the current bedding shows that the material was washed into the channel fairly rapidly.

The Middle Calcareous Grit is dominated by the massive, poorly fossiliferous sandstone near the base, and the higher beds, though not so lithologically varied as the Hambleton Oolite beds below, frequently contain highly fossiliferous lenses, or thin bands of grey limestone, shell debris and oolite. The massive sandstones of the Middle Calcareous Grit form the greater part of the wave-swept Brigg which, on its south side, is largely covered with dislodged blocks of these rocks. They give rise to a short cliff on the north side and the underlying Hambleton Oolite beds occupy a narrower belt below ; they weather out as a series of successive narrow platforms. The north-western part of the Brigg is occupied by the upper beds of the Lower Calcareous Grit ; the soft sandy " Ball Beds " weather easily and give rise to wide platforms on the surface of which the more resistant calcareous doggers stand out prominently.

The distribution of the sub-divisions of the sequence on the Carr Naze and Brigg is shown in Fig. 41. The present Brigg is only the worn remnant of a former, more massive structure and within historic times large mounds of boulder clay contributed to its spectacular character—these have long since been washed away. The faunal elements of the whole sequence from the top of the Lower Calcareous Grit up to the disturbed basal beds of the Osmington Oolites present many peculiarities. There are heavy, thick-shelled forms of some species and thin-shelled dwarfs of others, while the general character of the fauna as a whole indicates a very shallow water environment. The dwarfing of many of the forms may be the result of low salinity of the water. Throughout these beds there is a striking abundance of tube-building polychaete worms—*Serpula intestinalis*, *S. lacerata*, *S. tricarinata* and *S. squamosa*—which were probably inhabitants of an intertidal zone, their tubes serving as protection and preventing desiccation.

Among the mollusca, *Trigonia triquetra*, *Gryphaea dilatata* and *Ctenostreon proboscideum* are present as large thick-shelled forms. Multitudes of *Exogyra nana* occur in every bed and also encrusting larger fossils ; *Lopha gregarea* is another common oyster. Burrowing forms like *Modiola bipartitus* and *Gervillia aviculoides* are also conspicuous ; the latter shows a gradual increase in size from the lower beds upwards until it becomes var. *megalomorpha* in the beds above the Filey Brigg Grit. This gradual increase in size probably indicates a steady increase in the lime concentration of the water until the conditions became ideal for its maximum development.

Species of *Chlamys*, *Lima*, *Astarte* and *Lucina* are not common and when present are often small and thin-shelled, and frequently

fragmentary or broken. While the thick-shelled lamellibranchs were able to endure the severe conditions of a very shallow near-shore environment the thinner-shelled forms were easily destroyed.

The small brachiopods *Rhynchonelloidea thurmanni* and "*Terebratula*" *fileyensis* are abundant and fairly stout; and judging by the relative size of its foramen the latter form was probably anchored by a thick, strong pedicle.

Gastropods are rare in the lower beds although such boring forms as *Natica* might have been expected in some of the sandy beds; however *Pseudomelania heddingtonensis* begins to appear in the beds above the Filey Brigg Grit and small, eroded micro-morphic forms are abundant in the wash-out in the top of these beds on the south side of the Carr Naze.

The occurrence of numerous ossicles of *Astropecten* and many fragments of the short-stemmed crinoid *Millericrinus echinatus* also point to shallow waters, while the little forms of *Paracidaris florigemma* found the sandy bottom not inimical during these early times though in its larger mature state it evidently favoured the more limy waters of the later Osmington Oolite episode. Flat forms like *Pygurus pentagonalis* and the starfishes would be better adapted to a rough environment than taller forms.

Along the coast northward from Filey Brigg the Corallian rocks gradually rise up from the sea floor into the high precipitous cliffs extending as far as Gristhorpe Bay. They form the vertical faces of the upper part of these cliffs which are unfortunately unapproachable for detailed examination; it can be said, however, that the Hambleton Oolites persist at the top of the cliffs as far as the small bay known as the "Wyke," some 4400 yards north of the Brigg; here they pass inland and are lost beneath thick drifts.

West of the Wyke the massive yellow beds of the Lower Calcareous Grit form the vertical upper part of Gristhorpe Cliff with the thick Oxford Clay forming a steep unstable slope below; and above it a variable thickness of boulder clay forms an equally treacherous surface. At Mell-Casty Hill, about 1500 yards west of the Wyke the Lower Calcareous Grit reaches the summit of the cliffs and its outcrop thereafter passes inland beneath the drift, leaving the Oxford Clay to form the constantly foundering cliffs as far as Yons Nab, some 800 yards farther north-westward.

On the west side of Yons Nab the Red Cliff Fault throws down the lower part of the Lower Calcareous Grit to the west so that it forms the uppermost part of High Red Cliff overlying the Oxford Clay and extending westward for a distance of 600 yards. Here again the Grit is unfortunately inaccessible for detailed examination. This is the last appearance of the Corallian beds along the coast until the Scarborough Castle promontory is reached about $3\frac{1}{2}$ miles farther north. Here, a mass of Lower Corallian beds is down-faulted to the east and has given rise to an impressive eminence

on which the Castle now stands. On the north side of the Castle Hill these beds are well exposed and the details of the sequence are as follows :—

SECTION ON THE NORTH SIDE OF SCARBOROUGH CASTLE HILL HAMBLETON OOLITE SERIES

Oolitic Limestones	ft. ins.
15. Current-bedded detrital oolites with fine shell debris disseminated throughout and also collected in lenticles and streaks. Purer oolites above	5 6
14. Soft oolitic clay parting	2
13. Hard oolitic limestone with comminuted detritus	4 6
12. Soft oolitic parting	2
11. Two hard beds of oolite	3 0
10. Soft oolitic brash-parting	2
9. Prominent hard limestone bed	2 6

The fossils from the above beds 9 to 15 include :—

<i>Exogyra nana</i>	<i>Pseudomelania heddingtonensis</i>
<i>Chlamys fibrosa</i>	<i>Nucleolites scutatus</i>
<i>Oxytoma expansa</i>	<i>Holactypus depressa</i>
<i>Gervillia aviculoides</i>	<i>Cidaris smithi</i> (spines)
<i>Chlamys splendens</i>	<i>Pentacrinus</i> sp.
<i>Meleagrinella ovalis</i>	<i>Pygurus pentagonalis</i>
<i>Trigonia</i> sp.	<i>Rhabdophyllia phillipsi</i>
<i>Cylindrites elongatus</i>	<i>Holcospongia floriceps</i>
<i>Pleurotomaria munsteri</i>	<i>Serpulae</i>

The *Gervillia* Beds

8. Two beds of hard detrital oolite separated by a line of soft brash ..	4 0
7. Soft oolite, becoming marly towards the base	1 3
6. Detrital oolite, the upper 6 inches standing out as a hard band ..	10
5. Thick bed of oolite with much detrital material	1 4
4. Variable parting of red clay with ooliths	2
3. Thick beds of detrital oolite, the lowest bed having a very irregular base	5 0

The predominant fossils in beds 3 to 8 include :—

<i>Gervillia aviculoides</i>	<i>Rhabdophyllia phillipsi</i>
<i>Chlamys fibrosa</i>	<i>Nucleolites scutatus</i>
<i>Chlamys splendens</i>	<i>Holactypus depressa</i>
<i>Exogyra nana</i>	<i>Cidaris smithi</i>
<i>Pleuromya uniformis</i>	<i>Millericrinus echinatus</i>
<i>Lima rigida</i>	<i>Pentacrinus</i> sp.
<i>Meleagrinella ovalis</i>	<i>Pseudomelania heddingtonensis</i>
<i>Sowerbya triangularis</i>	<i>Pleurotomaria munsteri</i>
<i>Lophia gregarea</i>	<i>Cylindrites elongatus</i>
<i>Astarte ovata</i>	<i>Rhynchonelloidea thurmanni</i>
<i>Pholadomya aequalis</i>	" <i>Terebratula</i> " <i>fileyensis</i>
<i>Proconia rhomboidalis</i>	" <i>Terebratula</i> " sp.
<i>Astarte subdepressa</i>	<i>Holcospongia floriceps</i>
<i>Oxytoma expansa</i>	<i>Serpulae</i>
<i>Trigonia</i> sp. (small perlate form)	

The Yellow Grits

2. Coarse, yellow to grey, gritty limestones containing much fine shelly material and sand, with softer, more ferruginous sandy partings becoming more numerous towards the base	10 0
<i>Goniomya literata</i>	<i>Gervillia aviculoides</i>
<i>Exogyra nana</i>	<i>Xysterella muricata</i>

<i>Gresslya peregrina</i>	<i>Nucleolites scutatus</i>
<i>Gryphaea dilatata</i>	<i>Millericrinus echinatus</i>
<i>Lopha? genuflecta</i>	<i>Rhynchonelloidea thurmanni</i>
<i>Chlamys fibrosa</i>	<i>Serpulae</i> , and fragments of
<i>Limatula corallina</i>	cordate ammonites
<i>Lima rigida</i>	

1. Irregular, hard and soft, yellow ferruginous sandstones with some disseminated detrital material and sporadic mis-shaped ooliths. Fossils present include those found in Bed 2 above along with *Modiola pulchra* and *Pinna lanceolata* 5 6

LOWER CALCAREOUS GRIT

- C. Thick mass of sand containing large rounded limestone doggers.
The "Ball Beds" 14 0
- | | |
|-------------------------------|-----------------------------------|
| <i>Protocardia intertexta</i> | <i>Pleuromya uniformis</i> |
| <i>Lima rigida</i> | <i>Pleuromya alduini</i> |
| <i>Chlamys fibrosa</i> | <i>Trigonia triquetra</i> |
| <i>Astarte ovata</i> | <i>Lucina lirata</i> |
| <i>Goniomya literata</i> | <i>Rhynchonelloidea thurmanni</i> |
| <i>Modiola bipartitus</i> | and ammonite fragments |
| <i>Pinna lanceolata</i> | |
- B. Hard cherty sandstone, rather sandy towards the base. Spicules of *Rhaxella perforata* common 3 6
- A. Thickly bedded buff gritstones in beds from 1½ to 3 feet thick .. 49 0
- | | |
|------------------------------|---|
| <i>Pholadomya hemicardia</i> | <i>Inoceramus nitescens</i> |
| <i>Arcomya rathieri</i> | <i>Cercomya undulata</i> |
| <i>Goniomya literata</i> | <i>Gresslya peregrina</i> |
| <i>Goniomya sulcata</i> | <i>Pleuromya alduini</i> |
| <i>Pinna lanceolata</i> | <i>Lucina lirata</i> |
| <i>Nucula oxfordiana</i> | <i>Nucleolites scutatus</i> |
| <i>Modiola bipartitus</i> | <i>Collyrites bicordatus</i> |
| <i>Thracia depressa</i> | <i>Rhynchonelloidea thurmanni</i> |
| <i>Trigonia triquetra</i> | Belemnite fragments and <i>Serpulae</i> |
| <i>Pteroperna polydon</i> | |

In this section the Hambleton Oolite beds show an increase in thickness over the equivalent beds in the Filey section, and the relatively unfossiliferous oolites so characteristic of this series farther west are well developed in the upper part of the section. The faunal characteristics and shallow water nature of the "Yellow Grits" and "Gervillia Beds" are also reminiscent of the lower part of the Hambleton Oolites at Filey.

(b) The Hackness Hills

At the eastern end of the Tabular Hills—the main area of the Corallian formation north of the Vale of Pickering—are the Hackness Hills, an outlier separated from the main area to the west and south by the River Derwent (Fig. 40). This area is dissected by numerous small streams and dry valleys which fan out from Hackness in all directions to the west, north and east with the result that the Corallian beds form a series of smaller outliers. On the dissected high ground are the hamlets of Suffield, Silpho and Broxa, with Hackness occupying the low lying central position on the Hackness Rock.

The Lower Calcareous Grit is best seen in the deep ravine at the head of Highdales Beck on Hackness Moor some 2750 yards north-west of Silpho, where the section is as follows :—

	ft.	ins.
3. Soft friable calcareous sandstone, weathering and breaking into small cubical fragments	15	0
2. Thick massive beds of calcareous sandstone	7	0
1. Alternating hard and soft beds of calcareous sandstone, with an occasional wet argillaceous bed, passing down through clayey sandstones to the Oxford Clay below	65	0
<i>Rhynchonelloidea thurmanni</i> , <i>Chlamys fibrosa</i> , <i>Exogyra nana</i> , spicules of <i>Rhaxella perforata</i> and poor casts of cordate ammonites are common in all these beds		

The above fossils are also prevalent in the 15 feet of calcareous sandstones seen in a small quarry at Reasty Hill, farther north on the edge of the Lower Calcareous Grit escarpment. A good section of some 20 to 25 feet of thickly bedded calcareous sandstones with intervening softer bands is seen in the roadside pit at the foot of Inn Moor, 1100 yards north-north-east of Suffield and about 17 feet of similar beds occur in a quarry on Scalby Nab, 950 yards south-east of Suffield. The fossils mentioned above are common in both these sections together with *Isognomon quadrata*, *Modiola bipartitus*, *Gervillia aviculoides* (small form), *Trigonia triquetra* and *Serpula*.

The lower beds of the Hambleton Oolites, formerly known as the Passage Beds, have been quarried in numerous places and used for dry-walling. They are thinly bedded, brown, impure gritty limestones with thin reddish brown clay partings along the bedding planes; often many of the beds contain a considerable amount of comminuted shelly material embodied mainly in the upper parts of the beds. Six feet of the beds occur in the small quarry (11¹) on the east side of Merricks Rigg where *Gryphaea dilatata*, *Exogyra nana*, *Chlamys fibrosa*, *Trigonia triquetra*, *Pentacrinus* sp. and *Serpula* were recorded. Seven feet of similar beds are also seen in the quarry (10) south-east of Thirlsey. In the large quarry at the south end of Merricks Rigg (19) the basal beds are 13 feet thick; they are more thickly bedded, darker and sandy with clay along most of the bedding planes and ground shelly material in the upper parts of some of the beds. Similar beds, 4½ feet and 15 feet thick respectively, are seen in the old quarry (9) north-east of Thirlsey and in the quarry (3) on Hackness Head; in the latter section the upper 6 to 7 feet contain two strong 3 to 4 inch seams of reddish brown clay. A little farther west of the last exposure three similar clay partings occur in the 15 feet of brown calcareous sandstones visible in quarry (4), two occur in the top 4 feet and the third parting is 4½ feet from the base of the section.

Overlying these basal impure sandstones and limestones with a

¹ Figures in parentheses refer to quarry numbers on Fig. 43.



FIG. 43.—THE OUTCROP OF THE HAMBLETON OOLITE CORAL-SPONGE REEF IN THE HACKNESS HILLS

very irregular contact is the Hambleton Oolite Coral Reef—a heterogeneous mass of lenses of compound corals, branching corals, calcareous sponges, large numbers of terebratulids and a host of other fossils—reaching a maximum observed thickness of 11 feet. This reef horizon has been mapped (Fig. 43); at the surface it gives rise to a characteristic type of rough stony clay land full of broken coral, sponge colonies and other fossils found extensively around the hamlet of Broxa and south-east and south of Suffield. In the outliers north of Hackness it has a wide dissected outcrop to the north of Silpho and eastward towards Suffield but along the steep flanks of the ravines the outcrop is very narrow.

It is well exposed in a small quarry (1) on the east side of Hackness Head where the following details were made out :—

	ft.	ins.
5. Coral-sponge reef—lenses and “roundheads” of compound coral with many sponges, terebratulids and other fossils in a matrix of soft buff mud	8	0
4. Three beds of soft brown sandy limestone with clay partings along the bedding planes. The bottom bed has a very irregular base ..	2	3
3. Variable red clay parting		4
2. Soft argillaceous sandy limestone		10
1. Thick brown calcareous sandstones with irregular ooliths and fine shell debris	10	0

A few yards to the south-west of this quarry is another section (3) where the reef is 11 feet thick and rests unevenly on 15 feet of brown granular calcareous grits with intervening thin partings of red clay in the upper part.

There are no exposures of the reef in the vicinity of Broxa or in its outcrop round the Silpho outlier. An old pit (8) north-east of Silpho is now almost completely overgrown. Another old quarry (18) at the south end of the Flock Leys outlier shows only 4 feet of the reef on 5 feet on calcareous sandstones, while in the quarry (9) 250 yards north-east of Thirlsey the reef is 3 feet thick with a 2 inch parting of black clay separating it from 4½ feet of underlying impure calcareous sandstones.

In a section (19) near the south end of Merricks Rigg the uneven upper limit of the reef is seen with small patches of the overlying oolite occupying the shallow depressions of this irregular surface (Fig. 44). Here the reef is only from 6 to 7 feet thick with some 13 feet of the usual impure calcareous sandstones below. By far the largest exposures in this reef occur in the ground to the south of Suffield (12), (13) and (14), where 7 feet of the lower part of the reef rest unevenly on varying thicknesses of the underlying impure calcareous sandstones.

From all the exposures in the reef mentioned above a large fauna has been obtained :—

Isastraea explanata and *Thamnasteria concinna* in lenses, colonies and isolated “roundheads,” *Thecosmilia annularis*, *Rhabdophyllia phillipsi*; *Holcospongia floriceps*, *H. polita*, *H. spp. nov.*, *Peronidella recta*, *P. spp. nov.*,

Blastinia aspera, *Corynella chadwicki*, *Lopha gregarea*, *Exogyra nana*, *Lithophaga inclusa*, *Chlamys nattheimensis* (small form), *Lima zonata* and *Xysterella muricata* comprising the reef fauna, together with *Chlamys fibrosa*, *Camptonectes lens*, *Pleuromya uniformis*, *Ctenostreon proboscideum*, *Astarte ovata*, *Lima rigida*, *Proconia rhomboidalis* (small form), *Ostrea quadrangularis*, *Velata anglica*, small spines of *Cidaris* (*Plegiocidaris*)? *smithi*, *Hemicidaris intermedia*, *Serpula tricarinata*, large numbers of "*Terebratula*" *fileyensis*, "*T.*" *kingsdownensis*, *Zeilleria hudlestoni*, *Terebratulina substriata* var. *suffieldensis* and *Thecidea* sp., and a small branched bryozoan.

The highest part of the Hambleton Oolites consists of fairly pure, evenly bedded oolites amounting to 30 feet. Four to five feet of these fine white oolites are seen in a quarry (2) on Hackness Head: they are poorly fossiliferous, having yielded only *Gervillia aviculoides*, *Exogyra nana*, *Ostrea* sp. and *Trigonia* sp. (cast). These

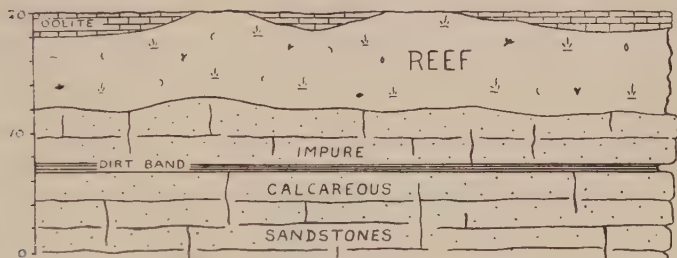


FIG. 44.—SECTION IN THE QUARRY NEAR THE SOUTH END OF MERRICKS RIGG, SUFFIELD.

beds are, however, best developed in the large Silpho Quarry (6) south-west of Silpho and two sections near Suffield—the old Suffield Lime Quarry (15) south-west of the village and the second one (16) some 200 yards away to the south-west. In the Silpho Quarry the section is as follows:—

	ft.	ins.
5. Fine hard white oolite	4	3
4. Variable clay parting		3
3. Fine oolites tending to be split by thin brashy partings along the bedding planes	4	6
2. Brashy clay band	3 ins. to	4
1. Thickly bedded fine-grained oolite	12	0

Among the fossils recorded from these beds are *Chlamys fibrosa*, *Gervillia aviculoides*, *Camptonectes lens*, *Exogyra nana* (particularly abundant in the clayey partings), *Pseudomelania heddingtonensis*, *Nerinaea* sp., fragment of a belemnite and a part of a cast of a cordate ammonite.

The succession in the large Suffield Lime Quarry (15), disused for many years, may still be seen as first described by Blake and Hudleston [12, p. 331], and may be summarised as follows:—

	ft.	ins.
3. Thin bedded shelly limestones with a poor micromorphic fauna ..	4	0

Xysterella muricata, *Exogyra nana*, *Lopha gregarea*, *Chlamys fibrosa*, *Trigonia* sp. and *Nucleolites scutatus*

- | | |
|--|----------|
| | ft. ins. |
| 2. Thick small-grained oolites with few fossils | 10 0 |
| 1. Fossiliferous suboolitic limestones with a megalomorphic fauna.
There may be some 6 to 8 feet of beds lying below the floor of the
quarry | 3 6 |
| <i>Oxytoma expansa</i> , <i>Isognomon quadrata</i> , <i>Gervillia aviculoides</i> and
casts of large ammonites. | |

In the neighbouring quarry (16) the series consists of marly oolites with intervening partings of soft brash; the details are as follows :—

- | | |
|--|------------|
| | ft. ins. |
| 11. Fine grey oolitic limestone with much disseminated detritus; very
shelly in the bottom 6 inches | 3 6 |
| <i>Exogyra nana</i> , <i>Camptonectes lens</i> , <i>Lopha gregarea</i> and <i>Gervillia
aviculoides</i> | |
| 10. Clayey brash | 3 |
| 9. Oolite with <i>Chlamys fibrosa</i> , <i>Exogyra nana</i> | 1 9 |
| 8. Brash parting | 2 |
| 7. Thin bed of oolite with <i>Exogyra nana</i> | 6 |
| 6. Parting of clay and brash | 2 |
| 5. Oolite | 1 11 |
| 4. Clay parting | 1 in. to 2 |
| 3. Oolite | 3 2 |
| 2. Clay parting | 1 in. to 2 |
| 1. Oolite | 2 6 |

In the bottom five beds *Exogyra nana*, *Chlamys fibrosa*, *Astarte ovata*, *Gervillia aviculoides*, *Pseudomelania heddingtonensis* and *Serpulae* are common, and an occasional cidarid spine is present. In places small patches of dark chert are not infrequent.

Through the absence of exposures little is known about the Middle Calcareous Grit facies in the Hackness Hills. It is an impure grey sandy oolitic limestone, very poor in fossils, and gives rise to a red clayey soil carrying much debris of the rock.

VARIATIONS IN GRAIN SIZE AND THE RANGE AND DISTRIBUTION OF THE SPICULES OF *RHAXELLA PERFORATA* HINDE

Thin sections of many of the beds, particularly from the coast sections, were prepared in order to determine the extent to which the spicules of the hexactinellid sponge *Rhaxella perforata* Hinde had:—

- (a) contributed to the formation of the Lower Calcareous Grit; and
- (b) persisted from Lower Calcareous Grit times and contributed to the building of the later sediments.

The examination of the thin sections has also yielded some interesting information on the size and character of the detrital constituents which must now be considered. The calcareous gritstones reveal that :—

- (a) the detrital constituents are subordinate to the matrix
- (b) the detrital quartz is characterised by irregular or no inclusions.

Quartz grains with no inclusions are the more abundant, and especially characterise the more finely grained beds ; it may be that the greater abundance of these grains is due to the detrition of larger grains with irregular inclusions along the lines of the inclusions.

In the Lower Calcareous Grit detrital material is fairly abundant, quartz grains predominate and an occasional fragment of felspar is present. The matrix is essentially calcite with some limonitic and clayey matter ; there is also a certain amount of siliceous cement, the distribution of which is very irregular. Many calcareous sandstones have a rough gritty weathered surface due to the solution of the cement at the exposed surface ; if, in addition, there is also a framework of interstitial siliceous cement this weathering effect is still more striking, and it is very characteristic of the weathered surfaces of the Lower Calcareous Grit being often seen in some of the higher beds on the coast.

In the coast sections the quartz grains are angular and up to .2 mm. in size, and they contain irregular inclusions, but in the Hackness Hills the grains are much smaller, averaging .1 mm. and less, and inclusions are less frequently visible. In the Lower Calcareous Grits at Scarborough Castle Hill there appears to be rather more detrital quartz than elsewhere and many of the grains are in contact. In the hard band immediately underlying the " Ball Beds " the quartz is mainly subangular though many angular grains are present and there are occasional rounded individuals ; they are not in contact and are in about equal proportion to the calcite matrix. The coarser character of the allogenic constituents on the coast points to derivation from the east. The fact that the grains are seldom in contact indicates contemporaneous cementation and continuous crystallisation during deposition.

When seen in thin section the Hambleton Oolite beds at Filey appear as mainly fine arenaceous shelly limestones with the angular quartz varying in size from coarse medium to fine grained. Some of the more oolitic beds contain considerable quantities of ground shell debris. In the Hackness district the brown ferruginous limestones forming the lowest part of the Hambleton Oolite series are largely composed of this broken shell detritus with about 5 per cent of angular quartz. In the oolite above, at Hackness and at Scarborough Castle Hill, the ooliths vary in size and shape and at the latter locality they are generally larger ; the calcite cement generally shows very little recrystallisation. Quartz amounts to 5-10 per cent of the rock and it is interesting to note that the grains are larger and more abundant than in the equivalent beds farther west towards Newtondale and Pickering.

In the sandy beds with the anastomosing structures commonly called " furoids " (Plate 10) in the Filey section the rock consists mainly of fine quartz grains frequently cemented by opaline silica ;

the "fucoids" are sharply defined and a section across an individual "fucoid" reveals the outer part as an arenaceous limestone containing 20-25 per cent of quartz; towards the centre the amount of detrital quartz decreases as the proportion of the spicules of *Rhaxella perforata* increases. Similar "fucoids" were described by Blake and Hudleston [12, p. 271] in the Sandsfoot Grit on the Dorset coast, and more recently Dr. Arkell [8, p. 63] has said of them, "it is not established that the appearances suggestive of fucoids cannot be produced by concretionary action."

At Filey the massive grits of the Middle Calcareous Grit contain abundant quartz in a matrix of calcite and limonite. The quartz is mainly subangular and for the most part the grains are in contact. In the Hackness area arenaceous limestones of Middle Calcareous Grit age contain subangular quartz grains with irregular inclusions in a calcite cementing medium, which has undergone slight recrystallisation, containing a high proportion of limonite.

In 1851, Sorby noticed certain reniform bodies preserved in agate together with small cellular bodies and sponge spicules in the Lower Calcareous Grit of the Yorkshire coast [38]; he estimated that there were about $2\frac{1}{4}$ millions of these bodies in a cubic inch of the rock and "I shall not be overrating them if I suppose them to constitute 20 per cent of the whole rock." In 1890 Hinde confirmed the presence of these globate bodies in this rock and considered them to be the spicules of a new hexactinellid sponge which he named *Rhaxella*, and described the species *Rhaxella perforata* [22]; in a later monograph he enlarged on this description. Since then calcareous and siliceous forms of the spicules have been recognised and described by Dr. A. Morley Davies [16] from the Arngrove Stone, where he has also recognised several variations in the preservation of the siliceous forms. The writer has also described several variations in the mode of preservation of the spicules in the Lower Calcareous Grit in the Howardian Hills in Yorkshire [45].

The spicules have their greatest distribution in the Lower Calcareous Grit throughout Yorkshire to such an extent in some localities as to form massive beds of light grey blue chert entirely composed of siliceous forms. In the coast sections siliceous and calcareous forms are disseminated throughout the lower, main part of the Lower Calcareous Grit, with the calcareous forms predominating in the blue limestone centred parts of these beds. The large doggers in the "Ball Beds" contain a high proportion of calcareous spicules intermixed with fine shell debris; spicules are absent from the sandy part of these beds.

In the Hambleton Oolite Series, calcareous spicules are locally abundant at Filey, and are rare in the equivalent beds at Scarborough Castle Hill. Occasional calcareous forms occur in the basal impure calcareous gritstones beneath the Hambleton Oolite



“FUCOIDS” ON HAMBLETON OOLITE, FILEY CARR NAZE.



Coral Rag in the Hackness area. The highest oolites of this series are devoid of these spicules.

Calcareous and siliceous forms are common in many of the more calcareous gritstone beds in the Middle Calcareous Grit at Filey.

THE PALAEOECOLOGY OF THE HAMBLETON OOLITE REEF AND ASSOCIATED SEDIMENTS

The remarkable faunal association of corals, calcareous sponges, terebratulids and their associated molluscan fauna in the Hambleton Oolite of the Hackness Hills can only be ascribed to the palaeoecological relations of the time, to understand which it will be necessary to see what guidance can be obtained from our incomplete knowledge of the ecology of the descendants of the fossil groups living in modern marine environments.

Twenhofel [41] has pointed out that "every organism lives where it does because the combined impact of all the environmental conditions permits it to live there. Animals in the sea organise themselves into communities of which the individuals are adapted to each other so that each constitutes a definite cog in the economy of the association." Agassiz [1, p. 10] observed how remarkable it was that the littoral fauna changes with the constitution of the bottom. What then were the environmental factors which allowed the calcareous sponges and terebratulids to form a reef community with corals in lower Hambleton Oolite times, an association which never again arose in subsequent Corallian episodes in Britain?

The great majority of the modern calcareous sponges occur in relatively shallow water from the tidal zone down to 30 fathoms, and nearly all of them live under conditions of good illumination in clear water free from mud, and according to Oakley [27, p. 335] they are often associated with sandy sea floors. They are sessile and incapable of locomotion in the adult state. In a recent study of the ecology of the porifera, de Laubenfels [17] points out that sponges living

amid rapid currents always lack pronounced surface elevations. The stronger the current the more nearly level will be the surface of the sponge. Where the currents are very violent indeed, the rule is that the sponges take what is called the encrusting form, extending laterally indefinitely, but never protruding far above the substratum and growing in a hemispherical or low rounded manner that is very characteristic.

Thus calcareous sponges living on the sandy and current-swept floors of warm shallow littoral seas are less regular and symmetrical than those of deeper water habitat and they usually encrust rocks, shells and other organisms or rest directly on the sea floor, under which conditions they reach their greatest abundance. de Laubenfels [17] concludes :—

What little evidence is available from references to polyphyletic fossil faunas bears out the theory that the ages have witnessed little change in

the methods whereby sponges react to their environments. It appears that in the past Porifera occurred in much the same environments as at present, and lived similar lives.

The first calcareous sponges invaded this area towards the close of Lower Calcareous Grit times but it was not until some time later that the Hackness reef was established. Their remains are first found in the top two feet of the Lower Calcareous Grit at Filey and while they persisted into higher beds in this area they were also migrating north-westward towards the Scarborough district, where they are first found in the lower Hambleton Oolite beds. A little later they congregated in a greater profusion of numbers and species under evidently more congenial conditions in the neighbourhood of Hackness. The fact that they are small rounded individuals or branching colonies without elevated oscula or other projections and many of the individuals, particularly *Holcospongia polita*, encrust other fossils, points to their living in shallow waters which were agitated and current-swept and in which little deposition was taking place. The relative numbers of the various species in a collection of over 300 specimens from the Hackness district are as follows :—

<i>Holcospongia polita</i>	214 specimens
<i>Holcospongia floriceps</i>	63 „
<i>Corynella chadwicki</i>	26 „
<i>Peronidella recta</i>	4 „

It is interesting to note that among the collections made by the Challenger and other dredging operations, the stations which yielded no calcareous sponges were consistently far from land and no stations which were a great distance from the nearest land yielded many sponges. It may be inferred that wherever fossil calcareous sponges are abundant in deposits of shallow water origin there was probably a land area not far away.

In their work on the Inferior Oolite sponges—mainly calcareous—from Gloucestershire, Richardson and Thacker [31, p. 163] conclude that “the rocks in which they were found were formed in shallow marine waters, probably near a coast,” probably the margin of the old Welsh geanticlinal land mass.

The present ecological distribution of brachiopods appears to be in harmony with their distribution in the past, excepting the rhynchonellids, of which the fossil forms had great development and distribution in shallow waters in bygone periods. On this subject Cooper [15] makes the following points :—

- (i) 60 per cent of living brachiopods species occupy shallow water but only little more than half this percentage is actually confined to shallow water.
- (ii) Terebratulids are the most abundant group living today, forming rather less than 70 per cent of the known genera and are mostly confined to shallow waters.

- (iii) Reefs are ideal habitats for brachiopods because the waters are warm, aerated and well lighted ; and corals associated with brachiopods in very fine muds point to shallow water.

He concludes that "except for bizarre types and unusual forms there is nothing to indicate that the brachiopods lived in the past in a manner different from that followed today."

Schuchert [33] had earlier expressed similar views that "brachiopods when large, thick shelled and abundant clearly indicate to the palaeontologist animals inhabiting very shallow waters of probably less depth than 100 feet. Further that these waters were in close proximity to the shores and probably were warm."

The occurrence of the robust globate terebratulids in such profusion in the Hackness reef and their presence with *Rhynchonelloidea thurmanni* in about equal numbers in the lower Hambleton Oolite beds at Scarborough and Filey further supports the view that these deposits were formed near land and in shallow water.

In recent years the detailed investigations by Dr. W. J. Arkell [2, 4, and 5] of the Corallian reefs in the Midlands have led him to the belief that while they were formed under conditions similar to modern reefs they grew at depths much shallower than 120 feet and in fact they "were formed at times when the sea-bed was all but nearest the surface of the sea and was still rising." He has further drawn attention to the small number of constituent species in our Corallian reefs compared with modern reefs, also pointing out that "the farther south we trace the Corallian beds and other oolites in Europe, the richer they become in reefs and the richer the reefs become in species, until in the region of the Jura Mountains we reach the metropolis of coral growth in Jurassic times" [5, p. 193]. In addition to being the metropolis of coral reef development this south-central European area was also the centre of the development of huge sponge reefs together with many other faunal associations on a grand scale both as regards numbers and species.

In the light of the above statements, attention may be drawn here to the virtual absence of calcareous sponges and terebratulids in the main episode of coral reef development in the Upper Corallian in this country ; their absence is the more unaccountable when it is remembered how they became established in considerable strength as reef builders along with the corals in lower Hambleton Oolite times in Yorkshire. It may be that the local conditions which were suitable for the association of sponges and corals in the earlier episode were not exactly repeated in later Corallian times.

Chemical precipitation of calcareous muds occurs at the end of the sedimentary cycle, clay—sand—limestone, when presumably the lime concentration is at its highest ; and, provided local environmental conditions are suitable, reef formation frequently

develops towards the end of the limestone facies and is associated with a profuse molluscan fauna, rich in species and individuals, all forms reaching a maximum size and attaining a maximum thickness of shell. A low salinity or any reduction in the salinity has an adverse effect and results in an impoverished fauna, poor in species and dwarfed in size though often rich in individuals, and along with the dwarfing of species goes a decrease in thickness of shell. Among euryhaline¹ animals, individuals living in reduced salinities frequently have a smaller maximum size than do those of the same species inhabiting more saline waters [39, pp. 840-2]. Corals are tolerant to a 20 per cent reduction in the salinity of the water of their normal environment.

According to the same authors [39, pp. 997-1004] there is a tendency for the calcium carbonate content of sediments to increase away from the coast, and in modern seas and sea bottoms the transition from sediments low in carbonate to those higher in calcareous material usually occurs within a relatively short distance. That this was true in Hambleton Oolite times is evident from the presence of shallow water largely arenaceous, sediments in the vicinity of Filey while at Hackness, a few miles away, a rich reef was immediately followed by pure oolites. It would appear then that, all other factors being favourable, the salinity and degree of lime concentration governed the rise and development of this unique Hambleton Oolite reef association; and, in summing up, the following points are made:—

- (1) Calcareous sponges thrive along with corals in waters of only just sufficient lime concentration for the active growth and metabolism of the reef building corals, but do not flourish in waters with a high degree of lime concentration. Even the corals are impoverished in so far as the compound forms do not develop into the huge massive colonies of later episodes but occur only as restricted lenses within the main reef mass.
- (2) The local profusion of terebratulids was also achieved in waters of not too high lime concentration; this is also supported by their presence in the equivalent sandy limestones at Filey and Scarborough where conditions were even less calcareous than in the vicinity of Hackness.
- (3) That the lime concentration of the water was not as high as it was during the formation of oolitic limestone muds is evident from the immature nature of some of the other elements of the associated fauna of this reef. Many of the species are small and thin shelled and few attain the usual size as found in the later Osmington Oolite episode, e.g., *Chlamys nattheimensis* and *Proconia rhomboidalis* are both small.

¹ "Euryhaline animals are those having a great degree of tolerance to wide ranges of salinity; they are naturally characteristic inhabitants of coastal regions and estuaries. The degree of euryhalinity varies greatly in different species" [39, pp. 840-2].

The Upper Corallian coral reefs grew at the end of a phase of calcium carbonate deposition; they were profuse in coral species and in the numbers and species of the associated molluscan fauna, but in this area the lower Hambleton Oolite coral-sponge reef grew relatively soon after the end of the sandy conditions of the Lower Calcareous Grit without any intervening deposition of limestone.

GEOLOGICAL HISTORY OF THE AREA

(a) Conditions of Sedimentation

Towards the close of the Oxford Clay episode the conditions of clay deposition began to be modified by the influx of fine arenaceous detritus. At first the change was gradual but as the quantity of sediment increased the dark muddy conditions were eventually replaced by clearer waters in which accumulated the calcareous gritstones of the Lower Calcareous Grit.

The influx of sandy material remained constant and uniform during the whole of this succeeding episode; the material was evenly distributed over the sea floor and a considerable thickness was laid down. Throughout this time vast numbers of the siliceous sponge *Rhaxella perforata* inhabited the sea and as they died and decayed their skeletal elements in the form of tiny globate spicules settled in myriads on the sea bed, where they formed a considerable part of the accumulating deposit.

At the end of Lower Calcareous Grit times the sea was shallow and the influx of material began to slacken on account of the general relief of the land supplying this detritus having been steadily reduced over a long period of time.

As the shallowing proceeded the sea floor came under the influence of wave and current action, and the critical point of deposition and erosion was reached where the sediments were only temporarily deposited and local non-sequences resulted. When sea level remained stationary for a time a base level of deposition was reached with the cessation of any further deposition until the conditions changed and a new base level was produced above the original one. These influences were more pronounced in the shallowest parts nearest to land. The gritty limestones and calcareous gritstones of the Hambleton Oolite Series—especially the lowest beds of the series—at Filey show abundant evidence of very variable shallow water conditions during these times.

The gradual reduction in the general elevation of the neighbouring land was reflected in the slow diminution of the quantity of detritus carried to the sea and correspondingly the lime concentration of the water slowly increased. Early evidence of the increase is provided by the tangled knots of serpulid tubes and the incoming of sporadic colonies of calcareous sponges—both indications of shallow water—in the top bed (Bed C) of the Lower Calcareous Grit at Filey.

In the Filey district conditions rapidly became extremely shallow, perhaps even intertidal, in early Hambleton Oolite times. A few inches of gritty limestone were deposited, cemented and hardened; wave and current action then prevented further deposition for a time, and the irregular, indurated surface of the bed is evidence of its also having suffered some degree of erosion. The currents were again modified or the floor sank low enough to be out of their range and, after whisks of mud and shell detritus had been washed into its surface irregularities, another bed of gritty limestone was laid down. The same process of hardening and scouring by waves and currents was then repeated. These unstable conditions prevailed for a time—represented by Beds 1 to 4—and were followed by similar slow shallow water deposition which, however, was not accompanied by intermittent erosion of newly formed deposits by strong currents.

In attempting a possible explanation of the peculiar “fucoid” layers it should be noted that:—

- (a) They occur in a condensed sequence of gritty limestones,
- (b) they adhere to the base of a particular bed and never to the upper surface, and often two layers of them occur one immediately above the other,
- (c) they are found only in these beds at Filey and not at Scarborough or elsewhere in these rocks in Yorkshire.

The end of the deposition of any bed is marked by its upper bedding plane, and the material for the formation of the next bed then begins to accumulate under normal conditions. If the sea recedes after the deposition of the initial layer of the new bed and it is exposed to the drying action of the air and sun it will develop a system of cracks. With the readvance of the tide and the resumption of deposition these cracks will be filled in, and it may be that the new infilling material contains a higher proportion of cementing matter, with the result that the infillings are better cemented than the surrounding sediment which has been cracked. This process may be repeated before the accumulation of the new bed becomes stabilised and continuous and, as in many instances, two sun-cracked layers occur one above the other.

If, as is here premised, these beds at Filey were laid down in very shallow intertidal waters the sun-cracked layers would be developed from time to time, but farther out to sea towards Scarborough deposition would be continuous.

When subsequently in a later age the sun-cracked layers are subjected, as at the present time, to weathering action or attack by the sea the less well cemented sediment would be most easily removed and leave the more resistant anastomosing infillings.

It is interesting to note that Dr. J. Bridge [13, p. 122 and Plate 15B] has observed and recorded many layers of similar structures

in the Roubidoux Sandstone of Ordovician age in Missouri, U.S.A., and he unhesitatingly states that they are the result of infilled sun cracks developed in the sandstone during its formation in very shallow water. I am indebted to Dr. Arkell for bringing to my notice a paper by Rieth [32] on similar "fucoids" found at four horizons in the Jurassic sequence in the Swabian Jura, and which are considered to be pseudomorphs after branching cylindrical and horn-type sponges. Rieth also thinks they are indicative of very shallow water conditions, and probably lived near the shore.

While, in the Filey district, the Hambleton Oolite deposits were of extremely shallow water and near-shore character, farther to the north-west in the vicinity of Scarborough and Hackness they retained their shallow water character but show no evidence of intraformational submarine erosion. At Scarborough the lower beds are detrital and similar in many respects to the equivalent beds at Filey, but the highest beds are thinly bedded detrital oolites—deposited in quieter shallow waters—a facies unrepresented at Filey.

In the Hackness district fine shell detritus and mud were laid down to a thickness of about 25 feet in the early stages of this episode until, perhaps through failure in the supply of the detritus or by reason of a radical change in the sea currents, the conditions were arrested and replaced by a quiet habitat in which a burst of organic activity took place. Or it may have been that the sea reached a degree of shallowness which, together with the other requisite factors,¹ was favourable to the development of a reef.

In these warm waters corals, sponges, terebratulids and associated organisms grew and lived in great profusion to form a unique reef. With the exception of the corals and some of the molluscs most of the organisms which contributed to and enjoyed the sanctuary of the reef had been living, perhaps rather precariously, through the early stages of the period in the shallower waters to the south-east of Hackness. This activity was only brought to a close when a further sagging of the sea floor carried the organic structure down to a depth at which the continued existence of the organisms became impossible and further development was abruptly stopped.

The sea was now rich in lime and later deposits laid down on the reef were pure oolites, at first in fairly thick beds, but becoming more thinly bedded and flaggy in the upper part. To the south-east in the Scarborough district the oolitic muds were not so pure, having a considerable admixture of shell debris and fine gritty sediment, whereas in the vicinity of Filey the corresponding beds have no oolitic character but were predominantly gritty limestones, with an occasional thin lens of oolite, similar to the underlying beds.

In the succeeding Middle Calcareous Grit episode a greater

¹ "Physical factors to which the marine animal must adjust itself include physical character of the bottom, temperature, depth, marine currents, salinity and amount of light. When any one of these factors in the physical environment falls below the minimum requirement of a particular species, elimination of that species from the facies results" [26].

influx of sandy material took place in the south-east and thick, partly wedge-bedded sandstones were laid down at Filey. Deposits of this age are absent at Scarborough, but to the north-west some of the finer sandy detritus was carried from the Filey district to be incorporated with the oolitic muds, the deposition of which still persisted in the Hackness Hills in Middle Calcareous Grit times.

(b) Palaeogeography

From the work of Dr. Rastall in Yorkshire [4, p. 581] it is inferred that the Dogger and Middle Lias were derived from the Fennoscandian land area which probably extended westward over part of the site of the present North Sea.

More recently, Dr. Smithson [37] has studied the grain sizes and distribution of the heavy minerals in the Middle Jurassic deposits of Yorkshire and he also concludes that they too were in part derived from a North Sea land area which reached at least as far south as the latitude of the Market Weighton axis. He visualises "a narrow land running parallel to the Pennine mass and not far removed from the present coast line."

Fox-Strangways [19, p. 283] has also drawn attention to the view of Godwin-Austen who considered that the greater part of the area of the North Sea was land during the oolitic period.

Again, in North Germany, Brinkman [14] and Schott [34] have thrown some light on the south-west extension of this ancient land mass and the extent to which it supplied sediment to the adjoining Jurassic seas covering that region. From their stratigraphical and petrological investigations they have shown that "at least from Vesulian to Kimeridgian times the bulk of the clastic sediment deposited in the North German sea was derived from the north. Every formation when followed from north to south passes from sand into clay" [4, p. 597].

In this country and particularly in Yorkshire there is little or no evidence indicating the probable extent of this land area towards our shores from Cornbrash to Lower Oxfordian times. But, in his description of the Hambleton Oolite and Middle Calcareous Grit beds at Filey, Hudleston expressed the view that they probably terminated not far to the south east; and though he did not express any such thought, he may nevertheless have visualised the existence of land in that direction at this time. It is now considered, on the evidence discussed in the foregoing account, that there was a western extension of this eastern land area in Hambleton Oolite and Middle Calcareous Grit times to within a short distance of our present shores of Yorkshire. Briefly summarised the evidence is as follows:—

- (a) The gritstones and sandy limestones in the Filey neighbourhood pass north-westward into purer calcareous rocks.
- (b) The grain size of the detrital quartz in these rocks diminishes in the same direction.

- (c) In the Filey neighbourhood the whole sequence is much condensed and there is evidence of repeated introformational erosion in early Hambleton Oolite times. At intervals, in the higher beds, the sea receded and the thin top layers of the sediments were frequently dried and cracked.
- (d) The fauna of these rocks, particularly at Filey, is of inshore shallow character, and at one stage in the Hackness district a reef flourished in rather less shallow water.

This land area, then, is visualised as being of fairly low relief and supplying a steadily decreasing amount of sediment to a wide, very shallow fringing sea from the end of Lower Calcareous Grit times to the end of the Middle Calcareous Grit episode. The water was clear and free from mud and was warm enough for the marginal coral-sponge reef to develop in mid-Hambleton Oolite times.

In the marine zone nearest to the land, at Filey, the sediments accumulated slowly with frequent intervals of non-deposition when the material was swept farther out to sea towards Scarborough and the north-west by offshore currents. There is no evidence to show that any such currents were at any time very strong or that they flowed in any particular direction; the evidence points to a uniform scouring of the sea bed having taken place at intervals in the Filey neighbourhood. Sometimes this scouring action only prevented the accumulation of sediment while at other times it was strong enough to erode the sea floor.

In Middle Calcareous Grit times an increased quantity of sediment was washed into the Filey area while farther away to the north-west the deposition of limy oolitic muds persisted from the later stages of the Hambleton Oolite Period with only little admixture of the finest sediment.

At the end of this episode, either no sediment was being carried to the sea from the reduced eastern land area, or its shores may have receded eastward so that the zone of sandy deposition in later times never reached the area that is now land in Yorkshire, for in the succeeding episode quiet limy oolitic muds were widespread over the whole of the Yorkshire basin.

PALAEONTOLOGICAL NOTES ON THE CALCISPONGIAE

More than 300 specimens of calcareous sponges have been collected from the various exposures of the Hambleton Oolite reef in the Hackness neighbourhood. They all occur in a matrix of fine mud which has to be removed before they can be studied. Much of this material can be removed from the specimen by repeated soaking and washing with water, but much of it is embedded in the fibrous structure of the sponge and in order to eliminate it other methods have to be devised. The use of dilute acids

was ruled out because they attacked the sponge structure. It was found possible, however, to remove a considerable amount of the interstitial mud by covering the specimens with powdered caustic potash which, on deliquescing in the atmosphere, draws out the fine muddy particles. The process is slow and laborious but eventually a specimen can be cleaned sufficiently for accurate detailed examination.

In the cases of forms like *Corynella* which possess a gastral chamber opening at the upper surface in an osculum the mud filling this chamber can be largely removed by dental appliances.

The following notes on the recognised species are intended to supplement the descriptions and notes on these species by Hinde [21], Siemiradzki [35] and Oppliger [28 and 29].

Holcospongia polita Hinde

Simple and compound sponges encrusting shells, echinoid spines and slender corals like *Rhabdophyllia phillipsi*. The open canals which radiate down the sides of the sponge from a depressed osculum on the upper surface are 15 in number; they are quite straight, of uniform width, and are radially symmetrical around the osculum. Traces of an outer dermal layer are occasionally present near the base of the sponge.

H. floriceps (Phillips)

Simple obtusely conical or subcylindrical and compound sponges, the latter being most common. The largest compound specimen collected has 10 individuals. They encrust shells, worm tubes and corals. The open surface furrows are from 6 to 10 in number, they are coarse and wide and frequently appear to be lined with a thin dermal layer though usually this has been weathered away. In most specimens the summit is truncated and the open canals are not symmetrically spaced down the sides.

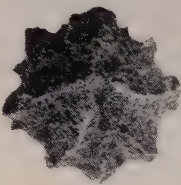
H. polita is distinguished from this species by its greater number of straight radially symmetrical open surface furrows, and by its difference in general form.

H. bernensis (Etallon) Plate 11, Figs. 4 a and b.

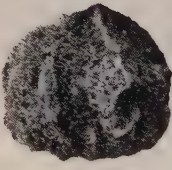
Two specimens of simple sponges which appear to belong to this species have been found at Hackness. They are identical with Oppliger's [28] Plate 1, Fig. 5A. In height they measure 8.5 mm. and 8.7 mm. respectively, and 14.4 mm. and 13.8 mm. respectively in breadth. The upper surface is flattened and from a shallow osculum radiate narrow irregular and often bifurcating, open canals down the sides. The surface canals have no radially symmetrical distribution. This Swiss species has not previously been recorded in England.

H. bella Hinde. Plate 11, Fig. 2.

One discoid specimen has been found which appears to be



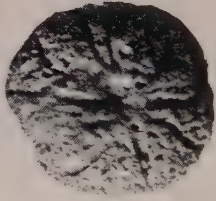
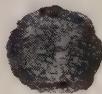
1^a
b



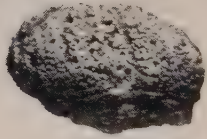
2



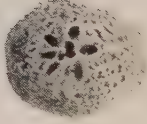
3^a
b



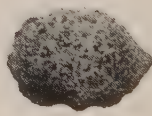
4^a
b



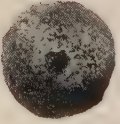
6



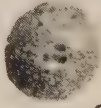
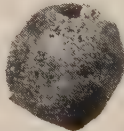
5^a
b



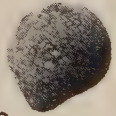
7



8^a
b



9^a
b



LOWER CORALLIAN CALCISPONIAE FROM N.E. YORKSHIRE.

[To face p. 267.

identical with this Inferior Oolite species. It is 7.4 mm. in breadth and 3.2 mm. thick with six open grooves radiating from the centre to the margin of the upper surface. The specimen has been encrusting a corallite of *Rhabdophyllia phillipsi*.

H. smithi sp. nov. Plate 11, Figs. 5 a and b.

Small hemispherical to globular, simple encrusting form. At the rounded apex is a central trefoil shaped osculum, and around are six short deep furrows extending in a symmetrical pattern from the rim of the osculum. The furrows do not appear to have any connection with the osculum. So far only one specimen of this species has been found ; it is 5.8 mm. high and 8 mm. in breadth, and its fibrous structure is open though delicate, resembling that of *H. polita*.

H. hindei sp. nov. Plate 11, Figs. 1 a and b.

This undoubtedly new species is a simple spherical form which appears to have had a stalk of attachment. The whole surface is cut up by wide deep grooves with intervening, sharply angular, irregular ridges. Four of the ridges converge to form a pointed apex ; the other ridges end at varying distances from this apex. In plan the specimen has a somewhat stellate appearance (Fig. 1 a) ; it is 9.8 mm. high and 10.2 mm. wide. Only one specimen is so far known.

H. suffieldensis sp. nov. Plate 11, Figs. 3 a and b.

Small, simple, spherical, encrusting forms with rather flattened upper surface carrying a slightly depressed osculum. From the osculum five canals radiate to varying distances down the sides, the longest canal never extends any farther than about half way down the side of the specimen while the shortest canal is little more than a wide gap in the margin of the osculum. The spicular structure is similar to that of *H. polita*. Of the four specimens collected the largest measures 11 mm. in height and 9.9 mm. in breadth.

Peronidella recta Hinde. Plate 11, Figs. 6 and 7.

Five specimens referred to this species have been found, two of which are illustrated. Three are single forms varying in length from 7.6 mm. to 17.8 mm. and from 4.7 mm. to 6.2 mm. in breadth. All, except one, have the pronounced truncated summit characteristic of the species, with the small circular cloacal aperture about 1 mm. in diameter.

P. hacknessi sp. nov. Plate 11, Figs. 8 a and b, 9 a and b.

Eight single specimens and one colony of two have been collected, which are spherical and encrusting in their mode of growth. Their summits are rounded with small circular cloacal aperture but in two specimens, one of which is figured (Figs. 9 a and b) this aperture has an inner trefoil-like form. The outer surface is smooth and the

spicular structure is similar to that of *P. recta*, from which this species differs in its spherical form.

Corynella chadwicki Hinde

The species exhibits a wide range of size and shape and all the specimens collected are of simple habit. There are straight and curved cylindrical forms, others are club-shaped to near spherical tapering gently to a broad flat summit occupied by a wide osculum. One globose specimen has a nodose swelling about half way down its side with a subsidiary depressed cloacal opening. The margin of the osculum is entire in every specimen with no traces of any open furrows radiating from it.

EXPLANATION OF PLATES 9—11

PLATE 9

NORTH SIDE OF FILEY CARR NAZE. Section at the entrance to the first doodle showing lower Hambleton Oolite beds and Middle Calcareous Grit overlying the "Ball Beds" (Lower Calcareous Grit).

PLATE 10

SLAB OF HAMBLETON OOLITE ON FILEY CARR NAZE SHOWING "FUCOIDS."
(Published by permission of the Director of the Geological Survey).

PLATE 11

LOWER CORALLIAN CALCISPONGIAE FROM N.E. YORKSHIRE.

- 1 a and b.—*Holcospongia hindei* sp. nov.
- 2.—*H. bella* Hinde.
- 3 a and b.—*H. suffieldensis* sp. nov.
- 4 a and b.—*H. bernensis* (Etallon).
- 5 a and b.—*H. smithi* sp. nov.
- 6 and 7.—*Peronidella recta* Hinde.
- 8 a and b and 9 a and b.—*P. hacknessi* sp. nov.

All the above specimens are in the Author's collection and are here reproduced twice natural size.

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DISCUSSION

Mr. P. C. SYLVESTER-BRADLEY welcomed the paper and particularly the detailed sections given of the Hambleton Oolite Series, which would be of great assistance to local collectors. He was interested to note that Dr. Wilson had detected rolled sponges in the Hambleton Oolite Series of both Castle Hill and Filey, and asked whether the author considered their presence sufficiently constant to provide a faunal distinction between the Coral Rag of the Hambleton Oolite and that of the much higher Osmington Oolite. It was the speaker's impression that even within the Hackness Hills the sponges were more abundant in the Suffield area than in the Silpho area.

The following written communication was received from Dr. W. J. ARKELL :

I welcome Dr. Vernon Wilson's study of the sponges of the Lower Corallian Beds of the Yorkshire coast. The group has been neglected in the past, perhaps because they have been outshone by the more conspicuous corals. A study of the unique sponge-coral bed of Hackness is particularly welcome. It is satisfactory also to have a thorough re-description of the Filey cliff section, so difficult to follow from the existing literature, which varies in age from half a century to nearly a century and a quarter. The chief value of the description is as a framework into which to fit stratigraphically the ammonites already collected by Dr. Wilson and to be collected in the future.

My hopes that ammonites would turn up in the Hambleton Oolites in the course of this investigation have not been realised ; but that makes the records that do exist all the more valuable, and in course of time finds may still be expected on the inland outcrops.

Since identifiable ammonites of zonal value have been found in the Passage Beds of Filey Brigg and Carr Naze, but not in the Hambleton Oolites, it seems a pity to abolish the long-established though ill-named Passage Beds and incorporate them in the Hambleton Oolites. For the present incomplete state of our knowledge there are by no means too many subdivisions. If there had been more in the past, ammonite records might have been more precise and therefore more helpful. Where the varied constituents of a formation are wedging out against a shoreline or an "axis" as here, there may be a number of surprises more or less concealed : such as the discovery that part of the Lower Calcareous Grit of Birdsall is younger instead of older than the Passage Beds of the coast. Only from ammonite finds can such conclusions be expected. The rest of the fauna has so long a range that detailed recording bed by bed serves little purpose.

In this connection it is relevant to mention that the *Rhaxella* chert (Arngrove Stone) of the Oxfordshire-Buckinghamshire border proved to contain an ammonite fauna belonging to the base of the Plicatilis Zone ; that is, later than both the Filey Passage Beds and the Birdsall Calcareous Grit. The *Rhaxella* chert at Purton, Wiltshire, although it has yielded no ammonites, probably correlates with the Arngrove Stone.

THE AUTHOR thanked the members for their kind reception of his paper. In reply to Mr. Bradley he said that he failed to see how there could possibly be any confusion between the reef developments in the lower part of the Hambleton Oolite and in the upper part of the higher Osmington Oolite ; the two developments are separated by a considerable thickness of sediment and their faunas differ in many respects.

Referring to the paucity of ammonites mentioned by Dr. Arkell, the Author said he knew of the existence of many ammonites being slowly eroded by the sea washing into the bedding planes of these rocks on the coast, but neither hand, hammer nor chisel can get between the beds to collect them !

FIELD MEETING AT NUNEATON

Saturday, 23rd April, 1949

Report by the Director : T. Eastwood, A.R.C.S., M.I.M.M., F.G.S.

[Received 6th May, 1949]

THE party of 30, which included members from London, the Midland Group and the newly formed North Staffordshire Group, assembled at Windmill Quarry, Tuttle Hill, where the Director gave a short account of sequence, structure and history of discovery in the district before proceeding to examination of sections. The sequence is Pre-Cambrian, Cambrian, Coal Measures, rising as a ridge through the Trias of the Midland Plain though the actual contact is chiefly a fault known as the Eastern Boundary Fault of the Warwickshire Coalfield. The throw of this fault, which brings Keuper Marl of the low ground against Pre-Cambrian and farther north Cambrian and Coal Measures, was at one time regarded as stupendous whereas it is of but a few hundred feet at most and near Nuneaton is little more than 200 feet, for there the Keuper Sandstone emerges from beneath the Keuper Marl and extends on the upcast side of the fault across the Cambrian on the Coal Measures.

The Pre-Cambrian, known as the Caldecote Volcanic Series, is made up of tuffs, ranging from fine green and purple ashes to a coarse quartz feldspar rock resembling a granite disintegrated and then re-cemented, pierced by numerous intrusions. These include the dark fine-grained diabase of the adjacent Blue Hole, camptonite sills common to both the Pre-Cambrian and Cambrian rocks and a dark variety of syenite known as markfieldite from the type locality in Charnwood Forest. The markfieldite was not exposed until the quarry was enlarged about 1930 by breaking through the basal Cambrian quartzite east of the Windmill towards Blue Hole. This exposure, described by Wills and Shotton (*Geol. Mag.* 1934, p. 512) is important, for it definitely proves that the markfieldite there (and by analogy that of Charnwood) is Pre-Cambrian in age, for lumps and pebbles of it are seen to be included in the bottom few feet of the succeeding quartzite. The eastern wall of the enlargement also shows the markfieldite to be penetrated by camptonite—a rather fine-grained rock of the diorite family.

After examining the section the party moved about 100 yards east to the Blue Hole, where in that old quarry the coarse quartz feldspar tuff is seen with an intrusive diabase. Adjacent trenches prove that the diabase is less extensive than previously supposed.

The party then moved obliquely across the quartzite to Hartshill (from which it derives its name) and Woodlands Quarry, which shows the junction between the quartzite and the succeeding Stockingford Shales. En route the large quarries in quartzite were noted, particularly those on the east where the basal quartzite has long been known to carry cobbles of the Caldecote tuffs.

In the early days the Hartshill Quartzite was classed as Millstone Grit and the Stockingford Shales as barren Lower Coal Measures. In 1882 Lapworth proved the latter to be Cambrian by finding trilobites and other fossils. During the six-inch survey just prior to 1914 the Geological Survey discovered *Callavia* at the junction of quartzite and red shales at the now obscured Camp Hill Quarry, thus proving the *Olenellus* or Lower Cambrian age of those beds. A little later Dr. Illing found *Callavia* in a similar position at Woodlands Quarry and also by trenching in the adjacent wood discovered an extensive fauna in the succeeding grey shales which includes *Paradoxides*. It is now established, therefore, that the Nuneaton Cambrian ranges from the lowest zone to Tremadoc.

In the main, the quartzite is a hard white or purplish rock in great demand as road metal, but the uppermost 50 feet, as exposed at Woodlands, is less indurated and would be more properly described as sandstone. The quarry is now flooded, but the eastern wall has conglomeratic layers in the sandstone and also a thin red and blue limestone with *Hyolithus*. Samples of this limestone were provided by Dr. Mitchell who took charge of the party between quarries. Some time was spent in unsuccessful fossil hunting on the heaps of red shales and then the party moved obliquely upwards in the sequence to the old school in Chapel End. Here there is a roadside section in grey shales with thin sandy bands invaded by camptonite. The ridge to which the latter gives rise provided a view across to the Coalfield with Ansley Hall Colliery on the skyline, the abandoned Chapel End ("Dry Bread") Colliery in the intervening hollow and old works to the right where Stockingford Shales were tried for bricks and tiles.

The Productive Coal Measures in this area succeed the Stockingford Shales with no great angular discordance. They are succeeded by about 150 feet of variegated Etruria Marls and these by 400 feet of the grey Halesowen Series, followed by red sandstones and shales of the Keele Beds.

The party walked through Chapel End towards Stockingford to see the multicoloured Etruria Marls with espleys ranging from fine sandstone to conglomerates and breccias exposed at Haunchwood brick pits near the cemetery, and at the pit east of the road where they are succeeded by buff-weathering Halesowen sandstone.

A visit to Stanley's clod pit, west of the canal, between Stockingford and Nuneaton completed the sequence, for here coal seams from the Seven Foot to the Bench in the lower part of the Productive Coal Measures were formerly worked in association with fireclays and mudstones for brick making.

The President (Mr. E. E. S. Brown) here proposed the party's thanks to the Director, to Dr. G. H. Mitchell, who had materially assisted in the arrangements and to Dr. J. F. Kirkaldy, who had acted as Secretary.

FIELD MEETING AT SEVENOAKS, KENT

10th July, 1948

Director : G. Austin Browne, F.G.S.

[Received 9th December, 1948]

A PARTY of 21 met at Bat and Ball (Sevenoaks) Station and went by way of Greatness Lane to the pits of the Sevenoaks Brickworks Ltd.

At the entrance to the Sand Lime Works of the brickworks the site of the overflowing borehole in Folkestone Sands was pointed out ; it supplies water to the adjacent watercress beds. The party made its way round the western side of the four-acre lake left by the removal of sand by the brickworks, and walked northwards along the tramway to the Gault Clay excavation.

The party was met by Mr. David Jones and also by Mr. Crook, Secretary to the Company, and demonstrations in brick-making processes were given. Mr. Jones has very kindly given permission for anyone interested to visit his pits. He would appreciate previous notice.

The Gault pit is worked along the strike (east-west) by a multi-bucket excavator. The pit is new to the Association, and is in Middle Gault.

On the return it was noted that some hard sandstone boulders had been brought up in the sand suction operations.

The President proposed a vote of thanks to the Director.

Map Reference : 6in. O.S. Sheet Kent 29 south-west.

The writer is indebted to Mr. R. Casey, of the Geological Survey, for identifying fossils collected from the Middle Gault, as follows :—

Coral, *Inoceramus concentricus* Parkinson, *Inoceramus sulcatus* Parkinson, *Nucula pectinata* J. Sowerby, "*Cardita*" *tenuicosta* (J. de C. Sowerby), *Anahoplites planus* (Mantell), *Anahoplites prae-cox* Spath (fragment), *Dimorphoplites* sp., *Dimorphoplites silenus* Spath, *Euhoplites inomatus* Spath, *Euhoplites* sp. *vulgaris* group Spath, *Dipoloceras bouchardianum* var. *alticarinata* Spath, *Hysterocheras* sp., *Hamites intermedius* J. Sowerby, *Hamites maximus* J. Sowerby.

NOTES ON WEALDEN BONE-BEDS

By P. ALLEN, M.A., B.Sc., Ph.D., F.G.S.

[Received 12th May, 1949]

SUMMARY—Present knowledge of the bone-bed succession in the Wealden of the Weald is summarised. Additional facts regarding the Telham ("Black Horse") Bone-Bed are given, and the Brede and Mountfield horizons are described for the first time. Local "bone-bed facies" of five other horizons are also mentioned. Detailed mapping suggests highly significant distributions for the Telham and Brede Bone-Beds. Their distributions and other characters are considered to indicate a large river entering the area somewhere to the north-east of Hastings.

INTRODUCTION

BONE-BEDS, containing abundant comminuted and rolled remains of vertebrates and invertebrates, are now known to occur at no less than four different horizons in the Lower Wealden (Hastings Beds) of Sussex and Kent. In addition, five other beds are locally very rich in vertebrate fragments. The proposed terminology, stratigraphical positions and relevant bibliography of the horizons are as follows:—

Upper Tunbridge Wells Sand

[Top Tunbridge Wells Pebble Bed (1*, pp. 91–3).]

Lower Tunbridge Wells Sand

[Top Lower Tunbridge Wells Pebble Bed.]

Wadhurst Clay

Mountfield Bone-Bed (p. 282).

[*N. medius* Shell-Bed No. 9 (2, p. 561)=Bed 9 of Fig. 47.]

Telham Bone-Bed (p. 279 ; and 1, p. 63 ; 3, p. 410 ; 4, pp. 64–8) Fig. 47.

[Brede *N. medius* Shell-Bed=Bed "G" of Fig. 46.]

Brede Bone-Bed (p. 276)=Bed "D" of Fig. 46.

Ashdown Beds

[Top Ashdown Pebble Bed (5)=Bed "B" of Fig. 46.]

Bone-Bed (6, p. 280. Exact locality and horizon unknown).

Horizons bearing only local "bone-bed facies" are shown in square brackets. They include the main pebble bed of each major unit of the Wealden sedimentary rhythm.

The present paper is primarily concerned with the Brede, Telham and Mountfield horizons. The first and last of these are new.

* For list of References see p. 282.

THE BREDE BONE-BED

Distribution and Relations

The Brede Bone-Bed is exposed at Hastings (Hall & Co.'s Quarry, West Marina, St. Leonards-on-Sea=Locality No. 31 of 7, p. 313), Brede (Hare Farm Lane=Locality No. 42 of 7, p. 314; and Stubb Lane=Locality No. 44 of 7, p. 314) and Beckley (Ludley Hill=Locality No. 53 of 7, p. 314); and possibly also at Iden (Oxenbridge Hill). As shown in Fig. 45, these localities lie on a

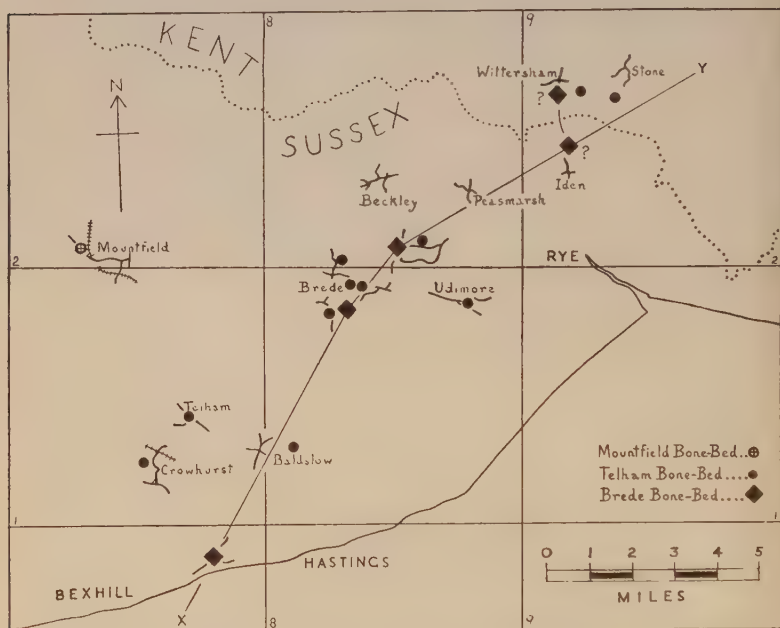


FIG. 45.—DISTRIBUTION OF LOCALITIES EXPOSING BONE-BEDS IN THE WADHURST CLAY.

north-east-south-west line 14 miles long.¹ Elsewhere (i.e., at 168 localities shown in 5, Fig. 2), the bone-bed has been sought in vain.

The bed lies in the Basal Wadhurst Siltstones and Shales, between the Top Ashdown Pebble Bed and the Brede *E. lyelli* Soil-Bed. At Hastings it is 2-3 feet above the pebble bed, but declines north-eastwards with the general thinning of the silts, to lie directly on the pebble bed at Beckley (Fig. 46). North-eastwards of Beckley the bed is not recognisable as a distinct unit; but a bone-bed facies of the pebble bed occurs at Iden.

¹ Since the above was written the bed has been found also at $\frac{1}{2}$ mile north-west of The Grove, St. Leonards-on-Sea, $1\frac{1}{2}$ mile north of Hall and Co.'s quarry.

The exact stratigraphical relations are best seen at the type locality in Hare Farm Lane, Brede. There, the bone-bed comprises thin lenticles of buff sand up to 2 feet long, 1 foot wide and 2 inches thick, elongated between north-north-east and east-north-east. The lenticles cut across the current-bedding of the surrounding siltstones and shales, and on top are bevelled off to a common level. Occasionally, thin partings of sand connect them above. Though no more than thin sprinklings of "bone-meal," these have proved infallible trails to new lenticles.

Rootlets from the overlying soil-bed pass through the bone-bed.

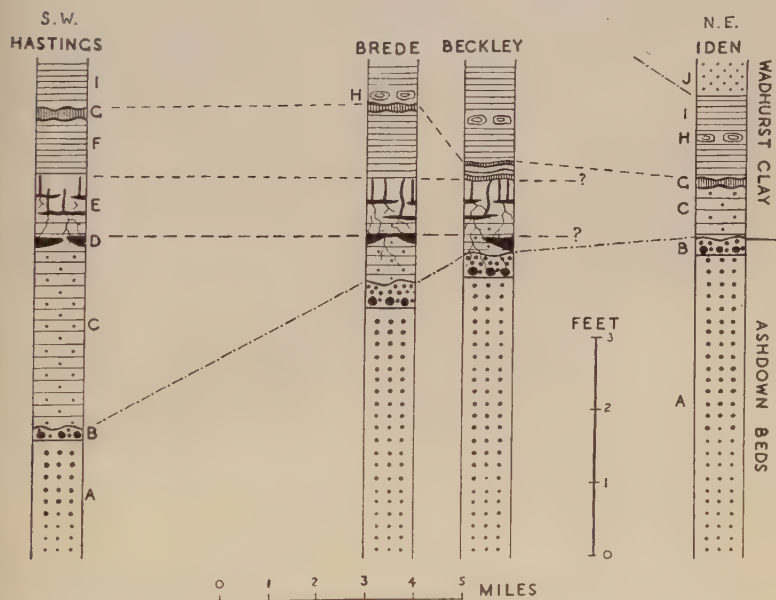


FIG. 46.—JUNCTION OF ASHDOWN BEDS AND WADHURST CLAY.—Diagrammatic sections along XY, FIG. 45.

- A = Top Ashdown Sandstone.
- B = Top Ashdown Pebble Bed.
- C = Basal Wadhurst Siltstones and Shales.
- D = Brede Bone-Bed.
- E = Brede *E. lyelli* Soil-Bed.
- F = Rust-mottled clay or shale.
- G = Brede *N. medius* Shell-Bed.
- H = Clay-ironstone nodules.
- I = Dark ostracod-shales.
- J = Sandstone or calcareous sandstone.

Lithology

In all four localities, the buff sand constituting the bone-bed is distinctive, contrasting markedly with the surrounding pale silt-stones and shales. It is non-pebbly, rather argillaceous and poorly sorted, and always contains bivalve casts (including *Neomiodon medius*). The detritus includes quartz and glauconite, mixed with large quantities of comminuted scales, teeth and bone varying in size from finest powder to fragments two inches long. The larger organic fragments sometimes lie at high angles to the bedding, occasionally even having their projecting tips buried in the abruptly discordant shales above. Petrologically, the bed is akin to the underlying top Ashdown strata [5].

Obviously the bone-bed fills wash-outs excavated during either (a) a non-sequence, or (b) floods, when an exceptional volume of water crossed the otherwise tranquil Ashdown-Wadhurst delta-plain.

Organic Detritus

Apart from specks of sooty lignite, the identifiable organic material in the bed consists entirely of mollusca, fish and reptilea. The following have been identified:—

Mollusca : *Neomiodon medius* (J. de C. Sow.). Casts of whole and broken shells.

Viviparus sp. Casts.

Fish : *Lepidotus* spp. Scales, fin-rays, fulcra, ribs and all types of teeth.

Hybodus parvidens A. S. Woodward. Teeth.

Hybodus spp. Fin-spines, teeth and unbarbed cephalic spines.

Reptilea : Chelonian fragments.

Crocodilean teeth.

Bone.

All are known to occur at Hare Farm Lane, Brede. Among the *Hybodus* fragments from Beckley, one cephalic spine measures more than 1 inch long. The late Sir Arthur Smith Woodward identified the vertebrates.

At each locality the fragments of different individuals and of different species are intimately mixed.

Interpretation

The broadly similar alinement of the lenticles and exposures must indicate movement of water along this direction (roughly north-east or south-west). This is confirmed by the eroded margin of the subsequent soil-bed, which is nearly parallel [7, Fig. 55], and by the distribution of the Telham Bone-Bed (Fig. 45). If, as Kirkaldy thinks, the bone-beds represent a "product of floods" [8, p. 387] sweeping over a maturing delta-plain, then a large river must have

entered somewhere to the north-east or south-west. This would assuredly have been one of the three major inflows of top Ashdown times [5]; and since the bone-bed also represents a stage in the general shallowing (ended by plant-colonisation), the fish may well have died, and their remains become scattered, *prior* to the first flood of water.

THE TELHAM BONE-BED

Distribution and Relations

Outside Telham [1, p. 63], exposures of bone-beds—apparently all on this horizon—occur at Baldslow [4, p. 67], Brede (Post Office; Kicker Wood; Reysons Farm; Cat's Nest, Broadlands), Peasmarsh (Waterfall Wood, $\frac{1}{2}$ mile north-west of Dinglesden), Udimore (Knellstone), Stone (Stone Hole quarry and Teigh Farm), and probably also at Crowhurst [3, p. 410; 4, pp. 64-8]. The last-named locality was not mapped by the author. Elsewhere, bone-beds appear to be absent. They thus lie in a north-east-south-west tract more or less coincident with the earlier bone-bed (Fig. 45). At every locality the beds rest on sandstones or calcareous sandstones overlying the dark ostracod-shales (with *Viviparus* and thin *N. medius* partings) which succeed the Brede *N. medius* Shell-Bed (Figs. 46 and 47). Above, alternating siltstones and shales always form gradual passages back to similar dark ostracod-shales.

The stratigraphical relations were recently (1939) best seen at the old "bluestone" quarry $\frac{1}{4}$ mile south-east of Reysons farmhouse, Brede. This was completely re-excavated just before the war. The vertical succession observed there is summarised in Fig. 47. It is typical of the sequence recorded everywhere in the Baldslow-Brede-Beckley-Udimore-Peasmarsh-Stone district. From time to time these calcareous sandstones have been worked (as "blue-stone" or "Tilgate stone") along most of the outcrops in the southern Weald.

Lithology

The bone-beds seldom exceed 2 inches in thickness (but locally reach 9 inches, as at Brede Post Office) and consist of ferruginous calcareous conglomerate or sandstone, more or less current-bedded and always resting on a hummocky surface of pale sandstone or calcareous sandstone. Shale or shaley silt (0-2in.) occasionally intervenes.

Quartz-pebbles occur abundantly at Telham, Baldslow, Brede (Post Office), Peasmarsh and Stone (both localities), and slightly *rolled* fragments of clay-ironstone (very similar to "H," Fig. 46), are common at Stone (Teigh Farm). Chert is everywhere subordinate. Apart from this, the most striking characteristic of the beds is their wealth of rolled and comminuted skeletal remains, varying in size from finest powder to fragments 1 or 2 inches across.

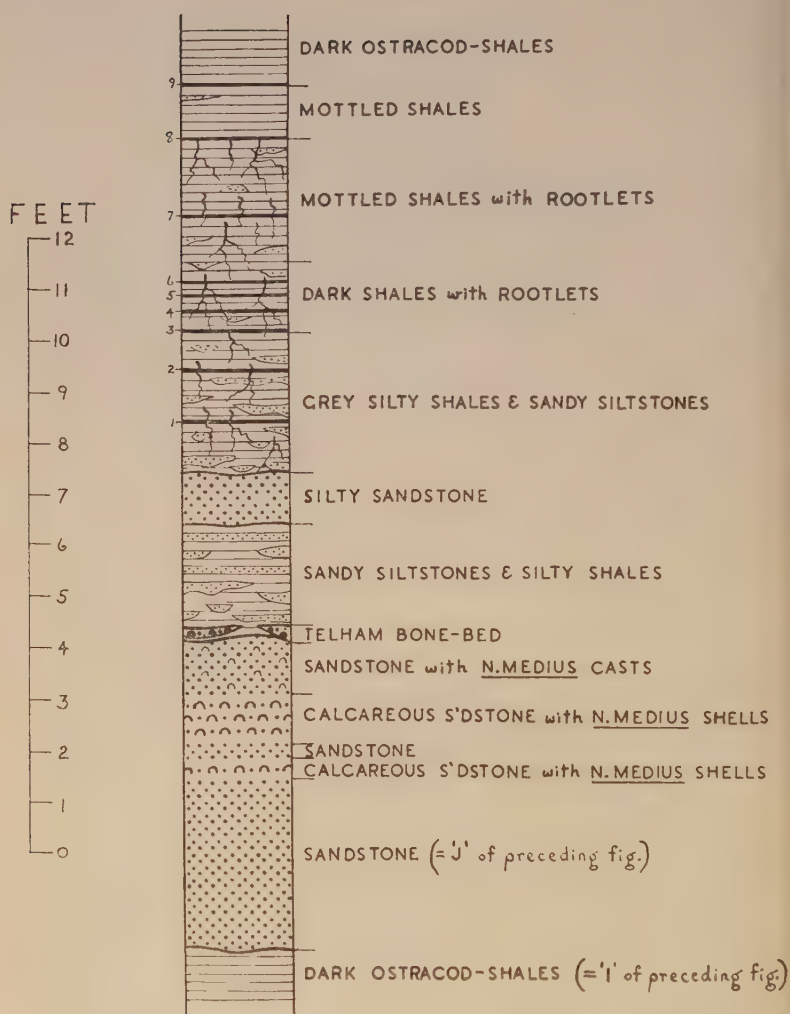


FIG. 47.—WADHURST CLAY.—GENERALISED SECTION OF BEDS EXPOSED AT REYSONS FARM, BREDE.

Main "bluestone" horizon of S.E. Weald. Calcareous nodules occur throughout the shales.

1—9=thin partings of *N. medius* shells. No. 9 is locally rich in fragments of bone, teeth, scales, etc.

As at Crowhurst [3, p. 411], the sandstones beneath have yielded quantities of fish and reptilean bones (Reyson's Farm, Kicker Wood, Knellstone and Stone Hole). The latter are often almost without signs of wear. Entire vertebrae, ribs and limb-bones of *Iguanodon* have come from all four localities, and nearly-complete skeletons of *Lepidotus* from Kicker Wood.

So similar are the stratigraphical relations and sequences at the various localities that a single horizon, the "Telham Bone-Bed," is thought to be represented.

Organic Remains

The organic debris differs markedly from that of the Brede Bone-Bed both in its greater proportion and in its greater variety. "Terrestrial" forms—reptiles and woody plants—are definitely more frequent. The complete list is as follows:—

Plants : *Equisetites* cf. *lyelli* (Mantell). Carbonaceous impressions of stem fragments.

?*Zamites*. Carbonaceous impressions of isolated and broken pinnules.

Other vascular plants. Casts and carbonaceous impressions of fragments of large and small stems and branches.

Mollusca : *Neomiodon medius* (J. de C. Sow.).

Neomiodon aff. *angulatus* (J. de C. Sow.).

Unio porrectus J. de C. Sow.

Fish : *Lepidotus* spp.

Hybodus spp.

Reptilea : *Tretosternum bakewelli* Mantell.

(Chelonia).

Plesiosaurus sp.

(Enaliosauria).

Goniopholis crassidens Owen.

(Crocodilea).

Suchosaurus cultridens Owen.

(Crocodilea).

Iguanodon sp.

(Dinosauria).

The late Sir Arthur Smith Woodward named the vertebrates. In addition, a great many fish and reptilean fragments defy identification.

It will be seen that several forms known at the type locality have not been found in the new exposures (cf. list given in [1] and [4]).

Interpretation

Since the same general explanation applies to this bed as to the earlier Brede Bone-Bed (pp. 278-9), it is necessary here only to point out the major differences and the more significant of the similarities.

First, the Telham Bone-Bed marks a considerable advance in current-competence and erosional power over the earlier bed. Doubtless this accounts for the presence of rolled ? Wadhurst

clay-ironstone and of a greater proportion of "terrestrial" remains in all grades. Second, the flow of water passed either towards the south-west or towards the north-east—a conclusion similar to that drawn from the earlier bed. The inflowing river was probably the same in each case, and lay either to the north-east or south-west. That it represented one of the main inflows of top Ashdown times [5] can hardly be doubted. This is confirmed by the abundance of glauconite, and by the relative absence of cherts among the pebbles—characters probably indicative of the north-eastern inflow.

THE MOUNTFIELD BONE-BED

This bed was observed in a temporary reservoir shaft near Castle Farm, Mountfield, less than 50 feet from the top of the Wadhurst Clay. It is a penecontemporaneous pellet-conglomerate 1–2 inches thick, occurring in a series of brightly mottled red and green shales and clays alternating with current-bedded lenticles of pale siltstone. The pellets are of green shale and clay, often angular, and set in a green clay or pale siltstone matrix. Highly rolled fragments of *Lepidotus* and *Hybodus* occur in all specimens, sometimes abundantly.

Complete absence of exposures precludes detailed mapping of the bed.

OTHER HORIZONS

No contemporary exposures are known in the highest and lowest beds listed (p. 275). The "bone-bed facies" of other horizons present special problems, and will be dealt with elsewhere.

CONCLUSION

The most striking characteristics of the Lower Wealden bone-beds are their virtual restriction to the south-east Weald, and their north-east–south-west alinement (where known). If their origin is due to periodic floods caused by high river-levels, the prolonged existence of one and the same river must be accepted as a likely possibility. The river must have entered from the north-east [5], for penecontemporaneous erosion there (instanced by removal of the Brede Soil-Bed (= "E," Fig. 46), attenuation of the Basal Wadhurst succession ("C"–"I," Fig. 46), and the presence of rolled clay-ironstone in the Telham Bone-Bed (p. 279)), was at a maximum. The persistence of this river through much of Wealden times is demonstrable on purely petrological lines [5, 9].

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AN ABNORMAL CHALK FORAMINIFER

By TOM BARNARD, B.Sc., Ph.D., D.I.C., F.G.S.

[Received 10th June, 1949]

SUMMARY—Unlike other free-living foraminifera some specimens of *Flabellina cf. angulosa* d'Orbigny from various zones of the Upper Chalk show a strong tendency to have adherent end chambers. This together with a change of ornament from smooth to a pustulose shell seems to be unique amongst foraminifera.

INTRODUCTION

DURING a preliminary study of foraminifera from the Chalk, contained in the A. W. Rowe Collections at the British Museum (Natural History), several abnormal specimens were found. Some of these showed interesting features, which are considered worthy of note. Many foraminifera are known to have irregular abnormal end-chambers, or to grow quite regularly until a certain stage is reached, and then suddenly to become irregular and begin a new pattern of growth.

Some species of *Ammodiscus* from the Lias and Oxford Clay continue planospirally for several whorls, until the end stage is reached, when the continuous tube suddenly turns back and continues in the opposite sense. This type of irregularity has also been noticed in some specimens of *Cornuspira*.

Amongst the polythalamous foraminifera many examples of irregularity may be cited. Specimens of ornamented *Nodosaria hortensis* Terquem, from the *davoei* zone of the Lower Lias, often have a regular growth broken by the appearance of a much smaller chamber, which seems to occur at any growth stage, after which the test returns to its original growth rate. In this case there is no apparent injury to the test.

Reversal in the sense of direction or coiling of the test has also been observed in some species of *Ophthalmidium*.

During a detailed study of the family Lagenidae the author has noticed a prevalent tendency for the end-chambers in many specimens to become abnormally small or abnormally large, but to keep the shape of the earlier chambers. The end-chambers of other specimens show an extreme irregularity in which the shape of the last bears little or no relation to those occurring earlier. These features are well seen in specimens of *Dentalina*, *Lenticulina*, *Planularia*, *Flabellina* and *Fronicularia*. Occasionally specimens of *Lenticulina* have their end-chambers arranged so that the axis of coiling of the spire is at right-angles to the earlier part of the test.

All the genera just mentioned are benthonic and free-living. As far as I am able to ascertain the change from a free-living to an adherent mode of life in the same individual has not so far been described.

Certain specimens of *Flabellina* have been found attached only by irregularly developed end-chambers and it is here proposed to describe some of these forms.

SYSTEMATIC DESCRIPTIONS

Flabellina cf. *angulosa* d'Orbigny

Description. Several specimens were selected from an abundance of this species, to illustrate the intergradation from the free to the adherent form.

(a) *Normal Specimen*. Plate 12, Fig. 1. (P.40270).¹

The initial megalosphere is a spherical chamber which stands out above the general flattened surface of the test.

Three chambers follow in a very loose spire, the sutures are rectangular, and raised above the chamber wall. The "apertures" of these chambers are marginal. The chambers are arranged so that they are distinctly evolute on the apertural margin, but taper towards and overlap onto the proloculum. This is the "cris-tellarian" growth-stage.

In subsequent regular chambers the aperture moves from the marginal to the central terminal position, and this is accompanied by a rapid change to the chevron-shaped chambers typical of the genus. The sutures remain visible but become less and less raised above the surface of the test. The edges of the test are arcuate and not straight as in many species of *Flabellina*.

The final slit-like aperture is on a thick cylindrical neck.

Horizon : *Belemnitella mucronata* Zone.

Locality : Tharston, Norfolk.

(b) *Specimen showing Abnormal Flabelline growth-stages*. Plate 12, Fig. 2. (P.40271).

The megalospheric specimen has the three initial chambers similar to the above. The specimen then shows a complete reversal in the direction of coiling. The fourth chamber overlaps onto the apertural margin of the earlier chambers, the aperture changes from this apertural margin to the opposite side which also becomes evolute.

Two regular smooth, curved, chevron-shaped chambers follow.

A change is also noticeable in the development of the sutures. In the earlier chambers the sutures are raised, later becoming level with the surface of the test and finally depressed below the surface.

Horizon : *Belemnitella mucronata* Zone.

Locality : Tharston, Norfolk.

¹ Registered numbers referring to specimens preserved in the collections of the Geological Department of the British Museum (Natural History) are shown thus : P.—.

(c) *Specimens with a "Ramuline" Trend.* Plate 12, Figs. 3, 4, 5. (P.40272-4).

These megalospheric specimens commence growth as in the normal form, but after a few chambers a completely different chamber with a "Ramuline" growth follows.

In the specimen (Fig. 3) the first and subsequent chevron chambers become swollen into globose chambers, at the same time there is a change from the unornamented initial stage to a hispid ornament.

In the specimen (Fig. 4) several hispid chambers, of unequal size, are developed. Another irregularity occurs here. After the initial regular stage, there follow two hispid chevron-shaped chambers arranged so that they are in a plane at an acute angle to the original planispiral development. The three last-formed chambers are arranged in a different plane almost at right angles to those that precede.

There are then three distinct planes of growth.

The specimen (Fig. 5) shows a development of the regular normal test, and three regular chevron-shaped chambers occur before an abnormality is found. Then the smooth unornamented chambers are followed by chambers ornamented with very strong pustules, much stronger than in the hispid forms.

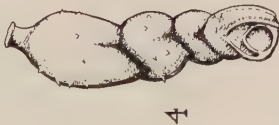
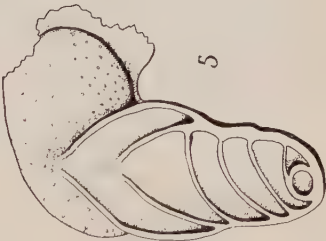
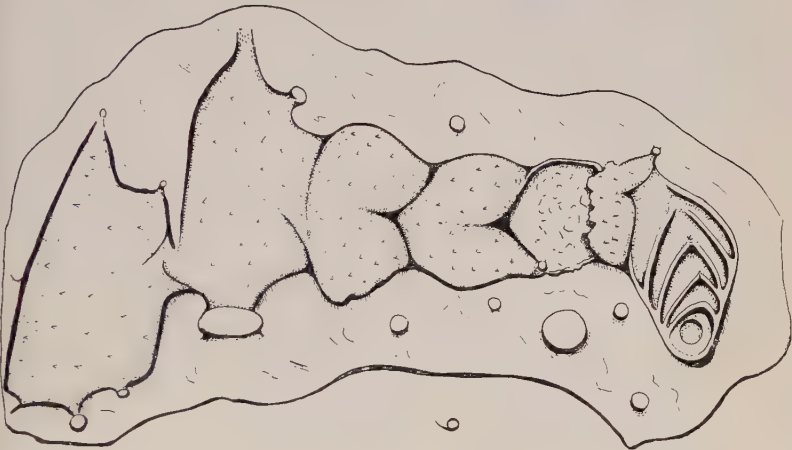
The first chevron-shaped chamber follows in the general direction of earlier chevrons, but this is followed by two chambers arranged in the same plane as those preceding, but at right angles to the general vertical axis of growth.

	Fig. 3	Fig. 4	Fig. 5
Horizon :	? <i>Belemnitella</i> <i>mucronata</i> Zone	? <i>Belemnitella</i> <i>mucronata</i> Zone	<i>Belemnitella</i> <i>mucronata</i> Zone
Locality :	Council's Pit Newmarket Road Norwich	Stonehill Kiln Norwich	Tharston, Norfolk

(d) *Adherent Specimen.* Plate 12, Fig. 6. (P.40275).

This megalospheric specimen commences with a swollen globose proloculum, which is followed by only one "crustellarian" chamber. Three normal chevron-shaped unornamented chambers follow, with raised sutures. This "initial" stage appears to be raised slightly above the surface of the echinoid to which the test subsequently adheres. At this stage no attachment to the echinoid can be seen, and it is highly probable that the test was free, as in the specimens described above. This portion of the test is then followed by nine chambers. At first these later chambers grow at right angles to the earlier direction of growth, but later the direction is meandrine.

All the chambers (except those badly preserved) show the "ramuline" pustulate ornament. Although still retaining a chevron-shape, the chambers become greatly swollen, so that in cross-section they appear almost hemispherical.



Growth stages of *Flabellina* cf. *angulosa* d'Orbigny.



The chambers are now distinctly adherent, and each possesses small calcareous protuberances which connect with the smaller tubercles and granules of the echinoid test.

Several specimens were found showing this character, so that the adherent trend in the "old-age" stage is by no means rare.

Horizon : *Belemnitella mucronata* Zone.

Locality : Tharston, Norfolk.

The writer wishes to thank Mr. C. D. Ovey for reading the typescript.

EXPLANATION OF PLATE 12

Specimens of *Flabellina* cf. *angulosa* d'Orbigny showing different growth-stages. All specimens magnified $\times 18$.

Fig. 1. This specimen shows the initial coiled stage, followed by a vaginuline growth-stage, and finally one flabelline chamber.

Fig. 2. The coiled and vaginuline stages are omitted, and the normal flabelline growth makes up most of the test.

Fig. 3. A young specimen in which the flabelline is replaced by a hispid ramuline growth-stage.

Fig. 4. Similar to the above but several hispid flabelline chambers make up most of test.

Fig. 5. A large specimen of normal form, coiled, vaginuline and flabelline growth-stages, followed by one swollen hispid chamber.

Fig. 6. This specimen has an initial shell composed of the three normal growth-stages followed by a number of adherent hispid chambers, the earlier of which still possess an inverted V-shape, in later chambers, however, this is lost. Small protuberances adhere to the granules and tubercles of the echinoid to which the foraminifer adheres.

A NOTE ON A SECTION OF COOMBE ROCK AND BRICEARTH AT ANGMERING-ON-SEA, SUSSEX

By B. W. SPARKS, B.A.

[Received 10th June, 1949]

SUMMARY—A temporary cliff-section in the superficial deposits of the Sussex Coastal Plain revealed some new details of the lithological composition of these beds, in particular of the gravels which lie between the Coombe Rock proper and the Bricearth. A small fauna of freshwater mollusca was obtained from lenticular beds of chalky silt lying within the gravels and evidence of human occupation from the Bricearth. On the basis of the lithology of the beds and the contained organic remains an attempt has been made to deduce the geographical conditions obtaining during their deposition.

DURING 1947 and 1948 a section of Coombe Rock and Bricearth, approximately 400 yards in length, was exposed in the low cliffs between Angmering-on-Sea (077016)¹ and a point on the coast immediately south of Kingston Farm (081015). This exposure was due to the destruction of the breakwater system, which allowed the sea to encroach some 20–30 feet in approximately 21 months. The whole section of cliff was completely boarded in during the late autumn of 1948 and is no longer visible.

In this district the Coombe Rock and Bricearth lie directly on the planed-down crest of the Littlehampton anticline, of which the Chalk is exposed in the foreshore but not in the cliff section. The latter, varying from 5 to 12 feet in height, was composed of the following beds:—

- (3) Bricearth. 3–8 feet.
- (2) Variable zone of unbedded, ferruginous gravels and impersistent, lenticular beds of chalky silt. 2–4 feet.
- (1) Coombe Rock. Up to 3 feet exposed.

The disposition of these beds is illustrated in Fig. 48, a generalised section based upon photographs and field sketches.

THE COOMBE ROCK

Only the uppermost few feet of the Coombe Rock were exposed, the junction with the variable zone of gravels being normally at high tide level. The deposit here consists of a weakly cemented conglomerate, composed of rounded chalk pebbles ranging up to 4 inches in diameter, and subordinate, battered angular flints. Parts of the Coombe Rock show rhythmic horizontal bands of staining due, probably, to the deposition of iron hydroxide by ground water

¹ Six-figure references are National Grid references.

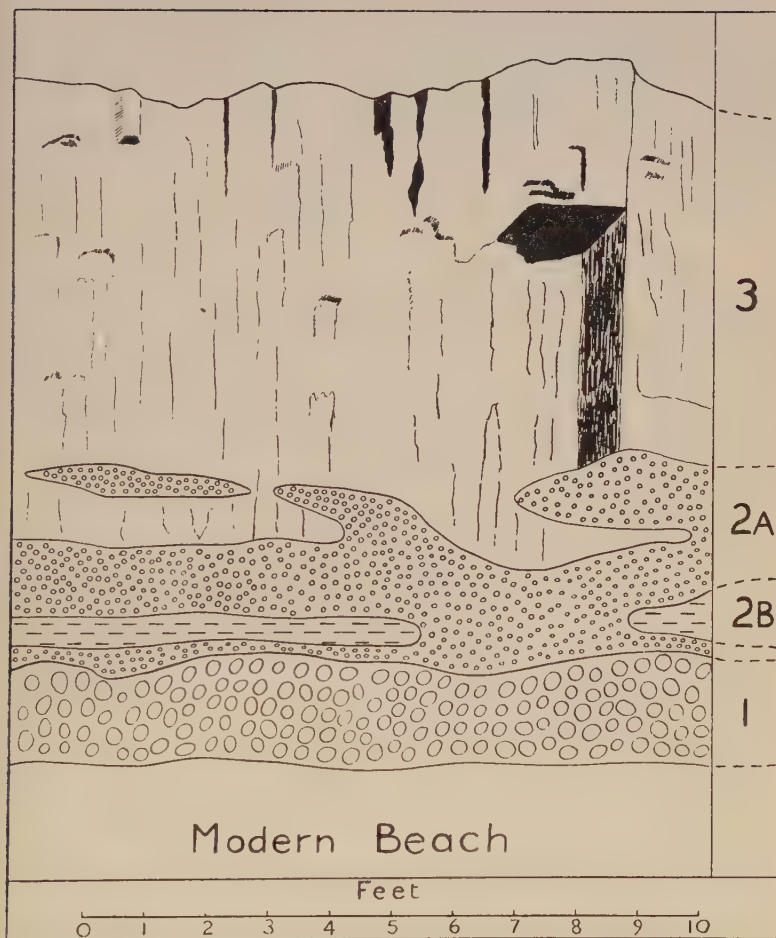


FIG. 48.—GENERALISED CLIFF SECTION NEAR ANGMERING-ON-SEA.

1. Coombe Rock. 2a. Ferruginous Gravels. 2b. Chalky Silt.
3. Brickearth.

filtering down from the Brickearth above. These bands traverse the chalk pebbles and stain the white cortices of the included flints.

THE FERRUGINOUS GRAVELS AND CHALKY SILT

This zone appears to correspond with Osborne White's upper, weathered zone of the Coombe Rock, which he describes as "brown, loamy gravel . . . gravelly loam, or comparatively clean brickearth" [5, p. 80].* Of the two component types of deposit, the ferruginous gravels always overlie the Coombe Rock, but, while normally occurring near the base of these gravels, some lenticular beds of chalky silt are found in the upper portion of the Coombe Rock.

(a) The Ferruginous Gravels

In the writer's opinion these gravels are not a pure residue derived from the weathering of the Coombe Rock, but a distinct deposit, as their composition is much more variable than that of the Coombe Rock. The gravel is ill-graded and pebbles range normally up to 1 inch in diameter, although individual pebbles attain much larger dimensions. The whole is set usually in a matrix of loam, occasionally in a matrix of sand. Several pounds of this gravel were washed through a 4 mm. sieve and the following constituents identified :—

(i) Flint gravel comprises some 98–99 per cent by weight of the deposit and consists of imperfectly rounded pebbles which show few signs of battering, although occasional larger pebbles appear to be battered beach flints. A rotted layer, normally less than 0.2 inches thick and iron-stained, is present on most pebbles, the centres of which range from black, translucent to brown, opaque.
(ii) The remaining 1–2 per cent of the gravel consists of the following :—

(a) Dominant, perfectly rounded, battered, black flint pebbles of 0.5 to 1.25 inches diameter, derived probably from the basement bed of the London Clay.

(b) Small, well-rounded, white to ochre quartz pebbles, usually of less than 0.4 inches diameter.

(c) Occasional pebbles of Upper Greensand chert derived from the Isle of Wight.

(d) Fragments of igneous rocks. One angular fragment, some 5 inches in length, proved to be a highly weathered, hornblende-biotite-granodiorite, in which the ferromagnesian minerals had been largely altered to chloritic minerals. The other, a rounded boulder 12 by 8 by 6 inches, was found to be a biotite-granodiorite, in which the brown biotite had again been largely altered to chloritic minerals.

(e) Broken fragments of *Cardium* sp., *Ostrea* sp., and a gastropod columella.

* For list of References, see p. 293.

(b) The Chalky Silt

These lenticular beds are composed of a grey-white, chalky silt, in which small limonite concretions are locally abundant. Washing and sieving of the material through a 1 mm. mesh yielded many small flint fragments and a number of small mollusca, all of which are freshwater forms still living in this country. The specimens, which have been presented to the British Museum (Natural History), have been identified by Dr. L. R. Cox and Mr. A. E. Ellis as follows :—

<i>Planorbis planorbis</i> (Linné)	1 specimen.
<i>Planorbis crista</i> (Linné)	1 specimen.
<i>Lymnaea</i> sp. indet.	2 broken specimens.
<i>Pisidium obtusale</i> (Lamarck)	Several specimens.

Mr. Ellis describes the last as “dwarfed and stunted, as though living under unfavourable conditions, e.g., subarctic with a short summer, as indicated by a very marked interruption of growth in some valves,” and adds that the species is known from the Pleistocene of West Wittering, West Sussex.

THE BRICKEARTH

The junction between the ferruginous gravels and the Brick-earth is a very irregular one, courses of gravel passing laterally into Brickearth. The main mass of the latter is an unbedded, buff loam showing a miniature vertical jointing, which is probably due mainly to the action of plant roots. In its upper parts occasional, thin, impersistent courses of rounded flints are present. The writer found no organic remains, apart from the Celtic ox and hearth noted below, in the Brickearth. His attention has, however, been kindly directed by Mr. E. C. Martin to a bed exposed some 50 yards from the eastern end of the section, from which Lang [2] obtained 17 species of non-marine mollusca including the Roman snail, *Helix pomatia* Linné. The bed forms part of a section visited by the Association in 1934 [3].

Approximately 130 yards west of the track leading from Kingston Farm to the sea, there occurs a saucer-shaped hearth-site, 5 feet in diameter and 2 feet in thickness at the centre, situated approximately 3–3½ feet below the surface of the Brickearth at an elevation of about 7 feet above high tide level. Ample evidence of its use as a hearth was provided by burnt clay, reddish burnt flints, burnt bone and disseminated charcoal. Bone fragments in the site, of which most were not identifiable, included fragments of the jaw and teeth of a young ox and similar remains of sheep. Some broken and blackened sherds of coarse pottery, made apparently from a mixture of clay and coarse sand (or ground flint), are probably referable to Iron Age A or Iron Age A/B (approximately 400 B.C. onwards). One flint pounding stone was also found

embedded in the site. Exotic stones present included one flat, water-worn, liver-coloured quartzite pebble cut by quartz veins of two generations, and some highly decomposed fragments of a vesicular lava, probably from Niedermendig in the Eifel region of North-West Germany. Such lava was imported from Neolithic to Saxon times mainly for use as querns.

Fifteen yards west of the track from Kingston Farm to the sea excellent sub-fossil remains of the small Celtic ox (*Bos longifrons* Owen), were discovered in the Brickearth at a depth of 3-3½ feet from the surface. The specimen was lying on its back on the ferruginous gravels, and had been entombed by the deposition of the Brickearth. Unfortunately the head was missing, probably due to marine erosion of the cliff, but a considerable portion of the skeleton was worked out, including one hind limb complete from the toe bones to the pelvis, many bones from the other limbs, ribs and vertebrae. The limbs, which reached to within 1½ feet of the surface, had been sheared through in places apparently by a plough. The specimen, which dates from the first few centuries B.C., is now in the possession of the Institute of Archaeology of the University of London.

From the evidence of this section the following picture of the geographical conditions, in which the beds were laid down, may be deduced. The main Coombe Rock has long been recognised as a sludge deposit formed under periglacial conditions during the last glaciation [4]. Towards the end of that period, with a slight amelioration of climatic conditions, the irregular surface of the Coombe Rock was covered with small pools, in which the chalky silt accumulated and in which the small freshwater mollusca lived. A further amelioration led to the deposition of the ferruginous gravels by braided streams following no fixed courses. The extraneous constituents, such as the Upper Greensand chert and the igneous rocks, were derived from the break-up of one of the raised beaches inland, probably the "15-foot" which is present in the area. Towards the end of the deposition of the ferruginous gravels the accumulation of the Brickearth commenced, the two overlapping to some extent as is indicated by the alternation of the two deposits. The unbedded nature of the Brickearth may suggest an aeolian origin, but the impersistent courses of rounded flints cannot be thus explained. In addition, the hearth site and small Celtic ox, both dating from the first few centuries B.C. and buried in 3-3½ feet of apparently undisturbed Brickearth, suggest that the accumulation of the Brickearth extended almost to historic times. Probably Osborne White's suggestion [5] that the Brickearth is a fine-grained wash from the Downs is nearer the truth, at least for the upper portion.

As a geological amateur, who has followed our President's advice [1] to record temporary sections, I wish to thank the

following for the help which they have so willingly given : Dr. J. F. Kirkaldy of Queen Mary College for constant assistance, Miss K. M. Kenyon, F.S.A. and Mr. I. W. Cornwall, B.A., of the Institute of Archaeology for identifying the pottery and the vertebrate remains respectively, Dr. L. R. Cox of the British Museum (Natural History) and Mr. A. E. Ellis for identifying the mollusca, Mr. D. W. Humphreys, B.Sc., for suggesting the origin of the cherts and Mr. E. H. T. Whitten, B.Sc., for identifying the igneous rocks.

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